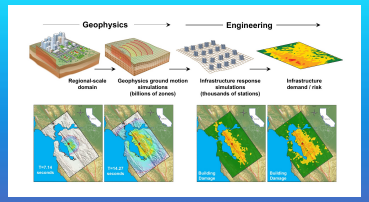


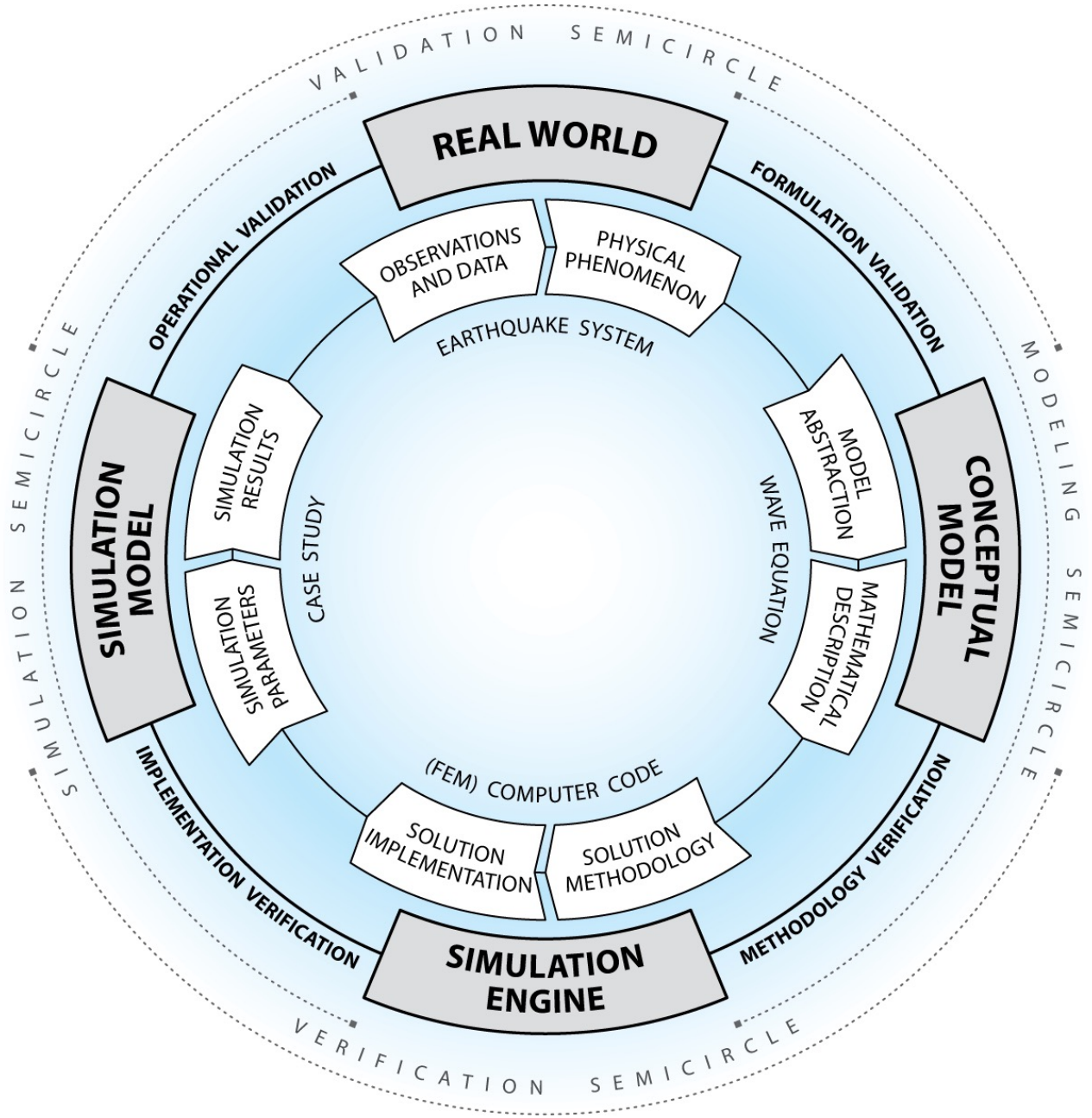
PEER International Pacific Rim Forum
June 16-17, 2021

Verification and Validation of Regional-Scale Ground Motion Models and Simulations

Ricardo Taborda
Universidad EAFIT

UNIVERSIDAD EAFIT®

PEER



R. Taborda (2008)

Operational **Validation**

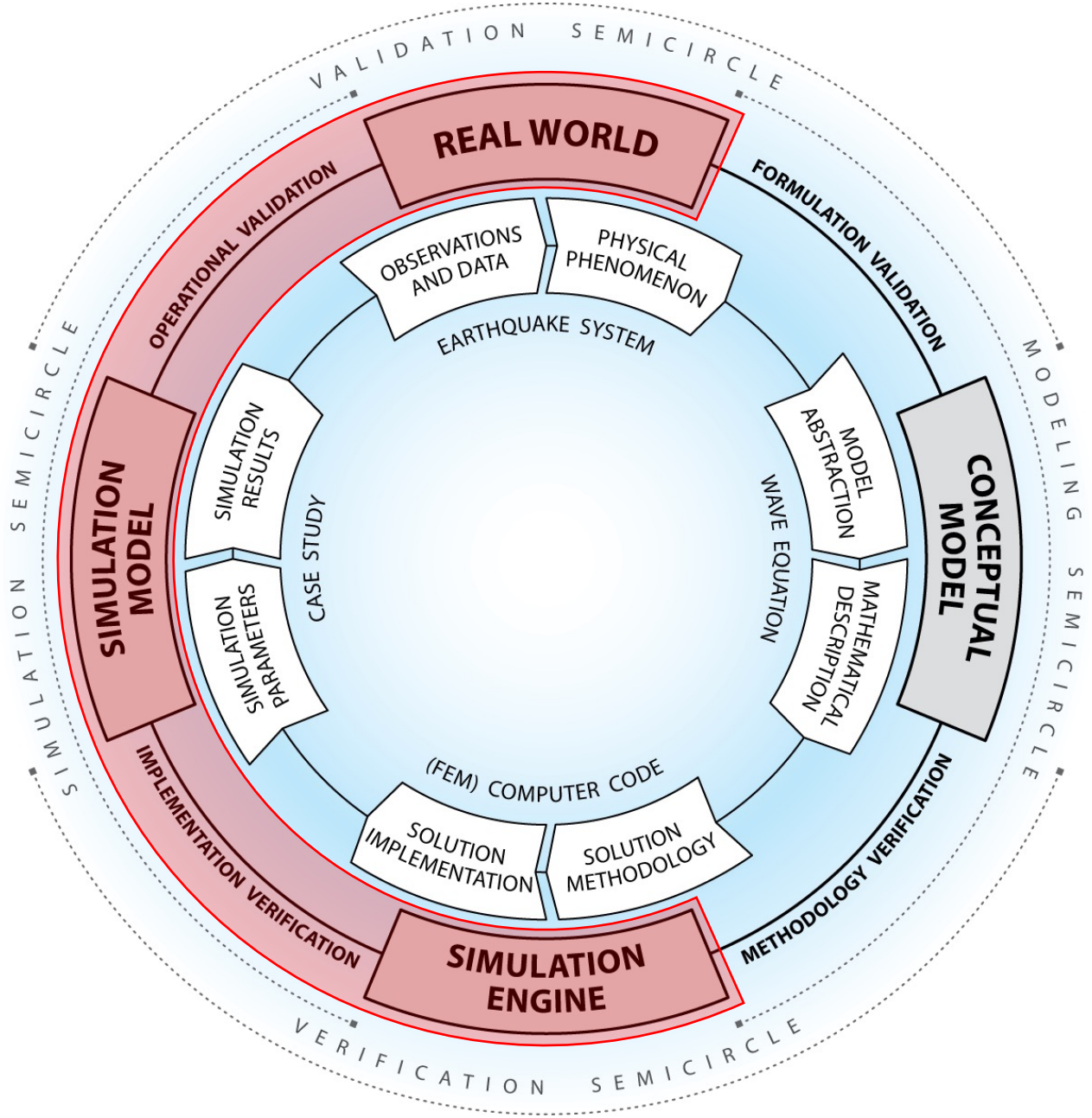
» Level of agreement between synthetics and actual data

» Comparison of simulations with observations

Implementation **Verification**

» Correctness of the implementation of a simulation scheme

» Comparison of simulations with exact or alternative solutions



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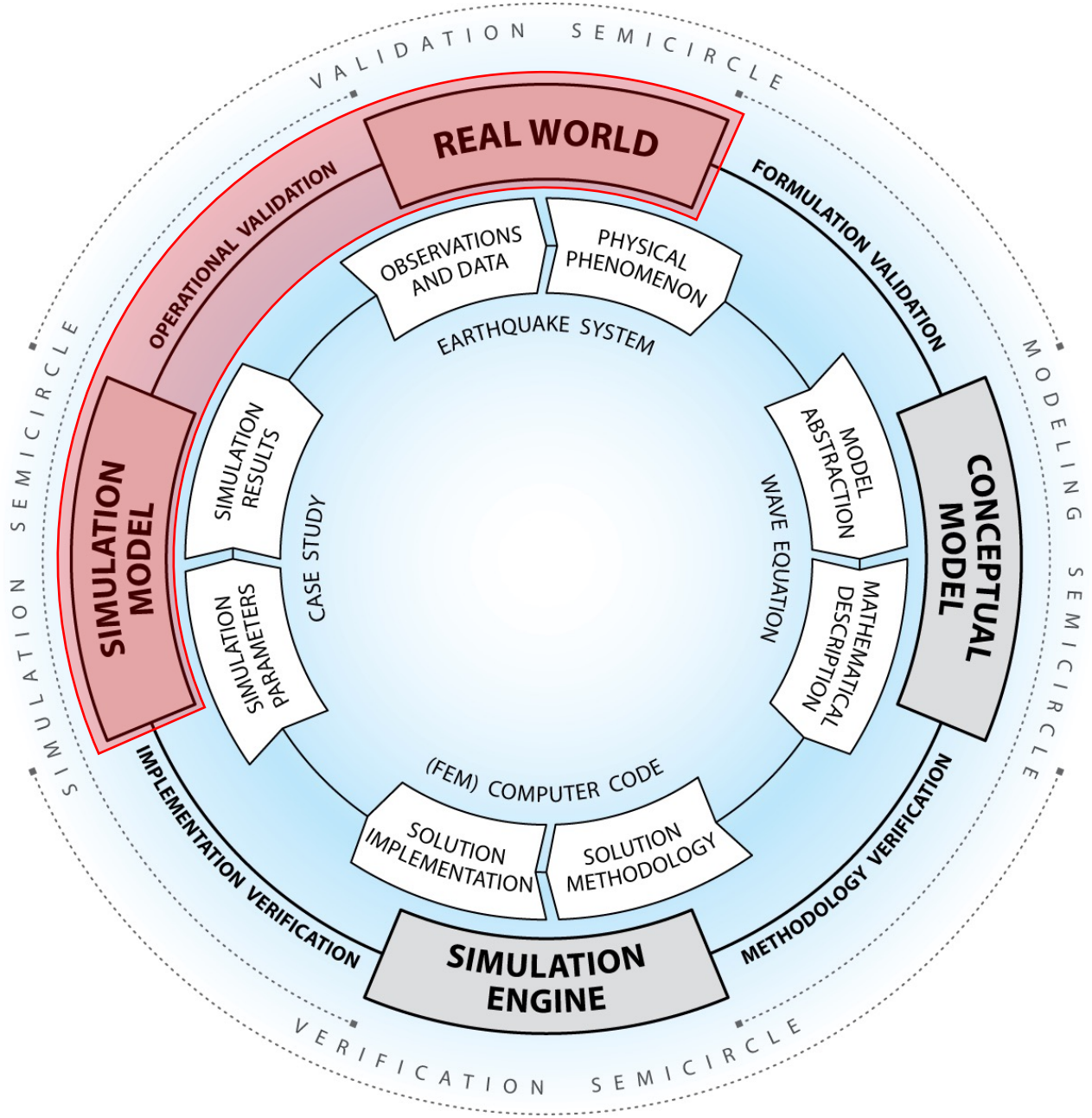
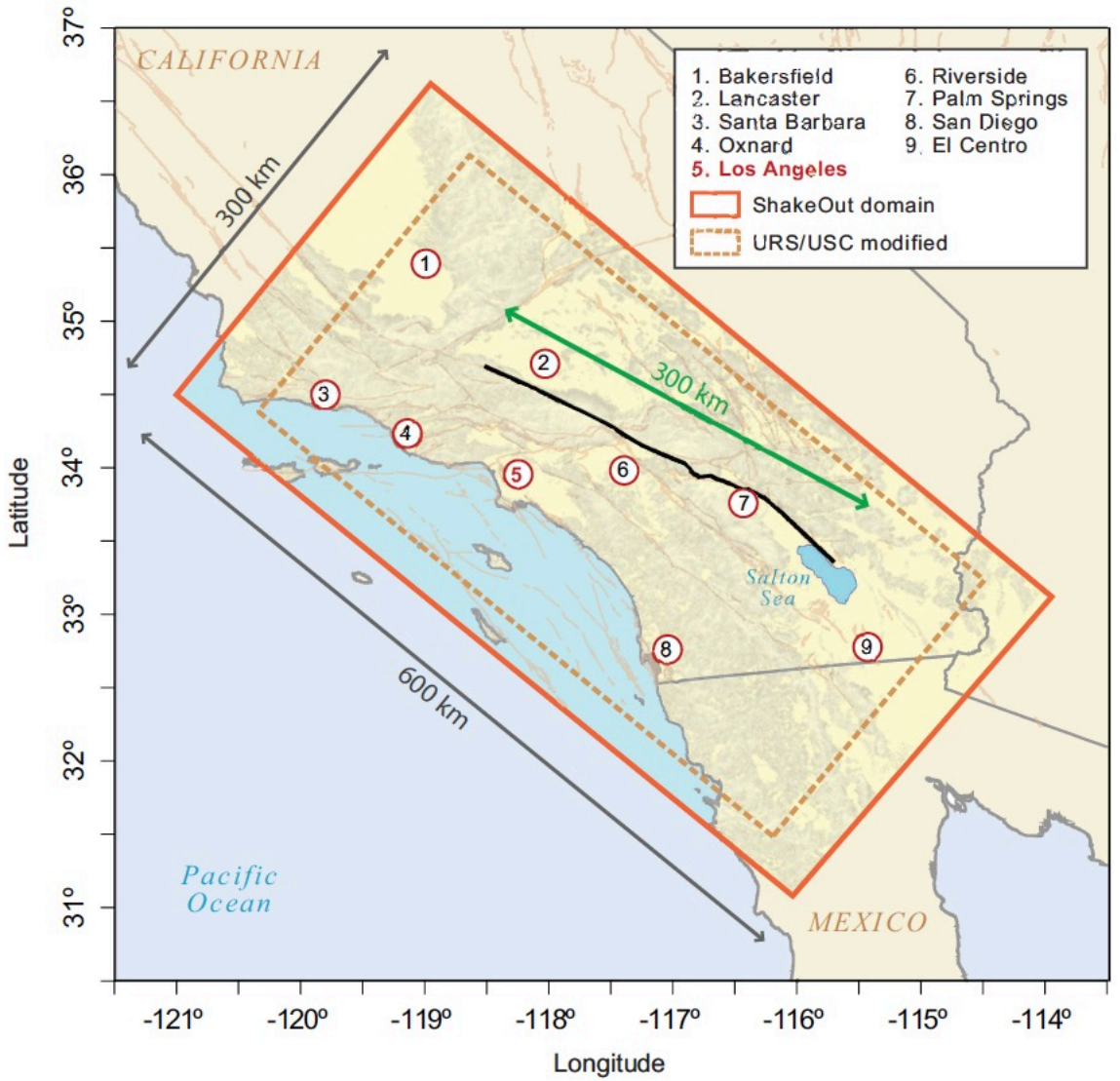


R. Taborda (2008)

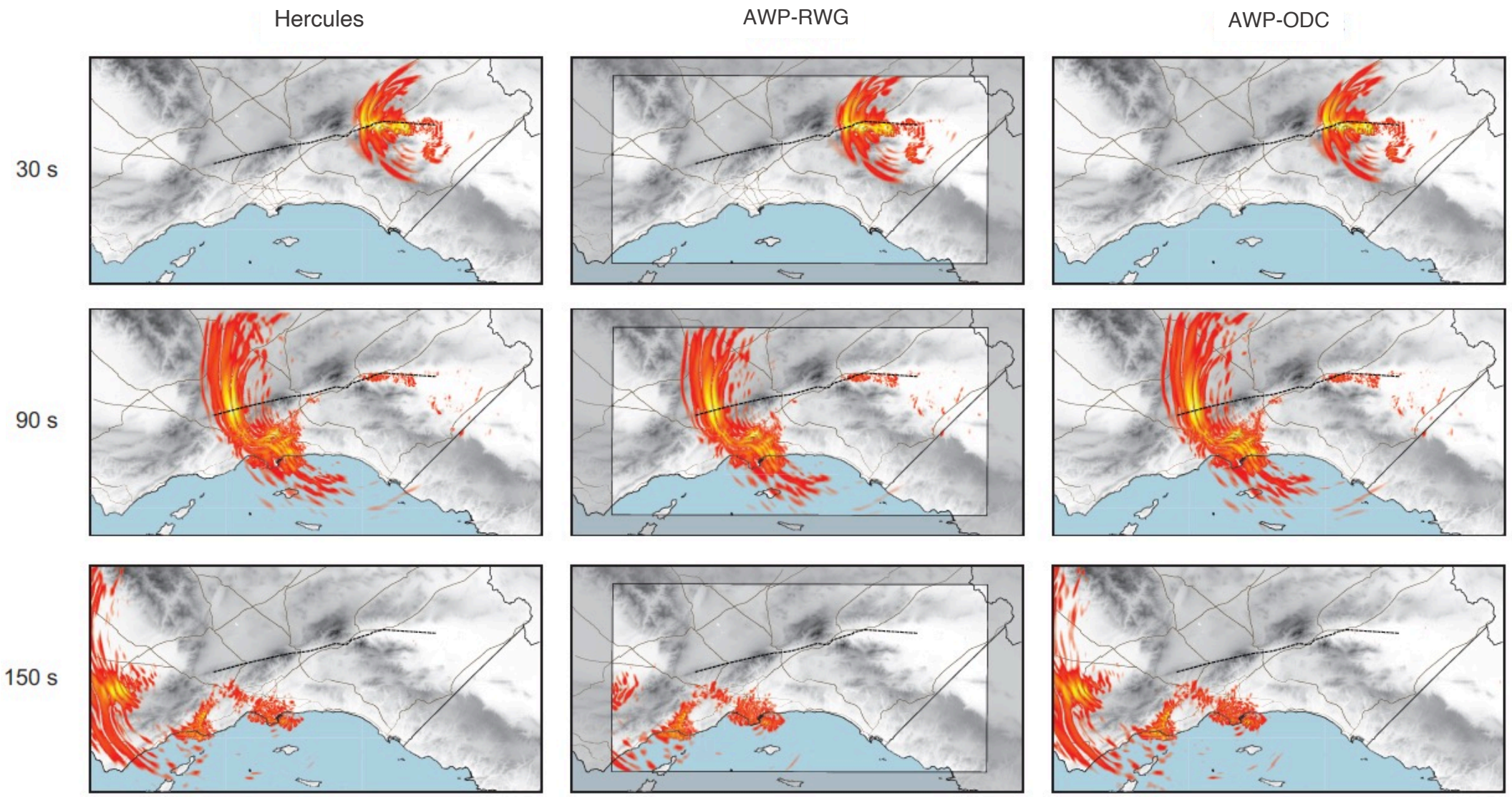
Legacy of the ShakeOut verification exercise

- 3 codes
- 0.5 Hz
- 500 m/s



Bielak et al. (GJI, 2010)

Qualitative verification



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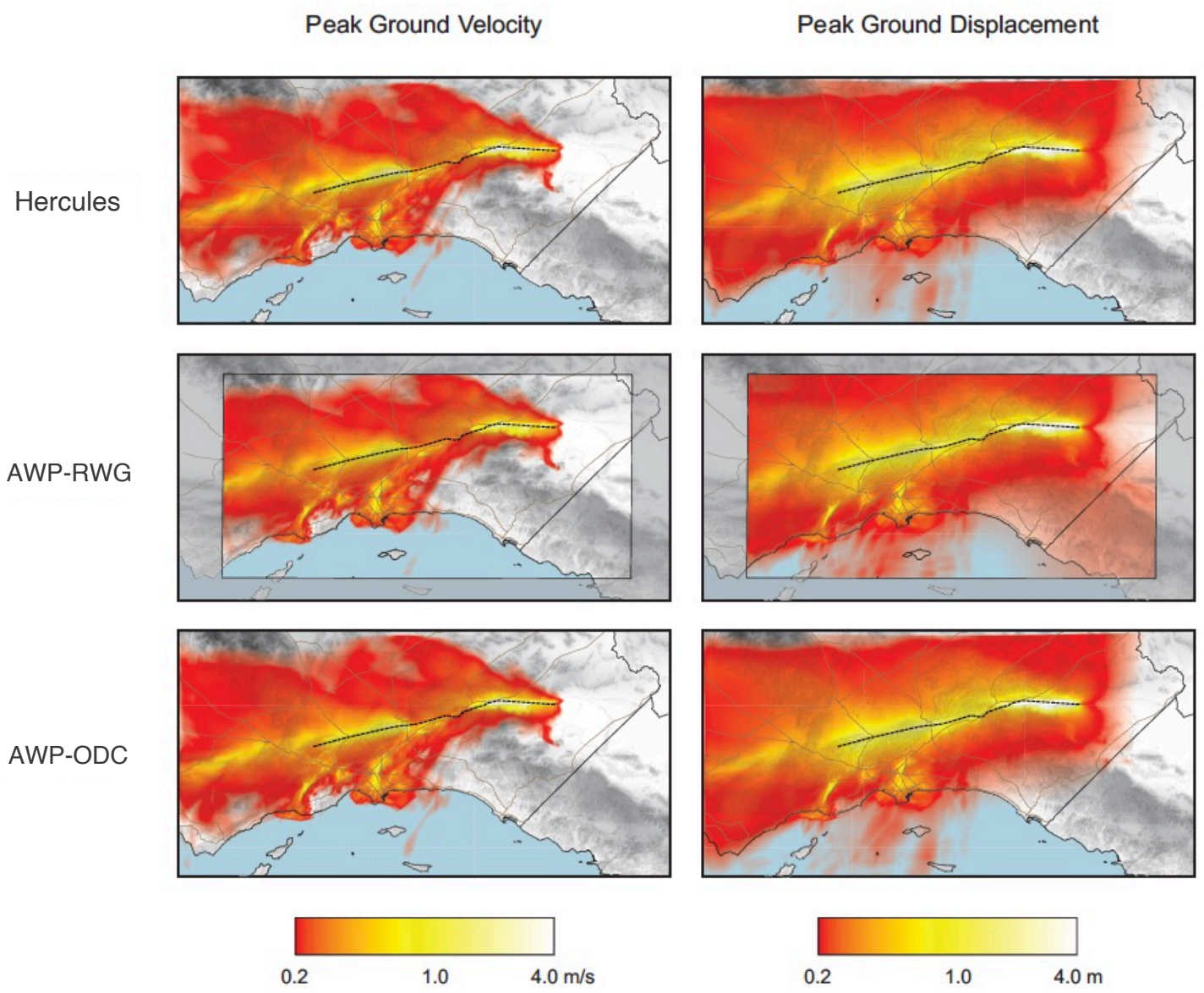

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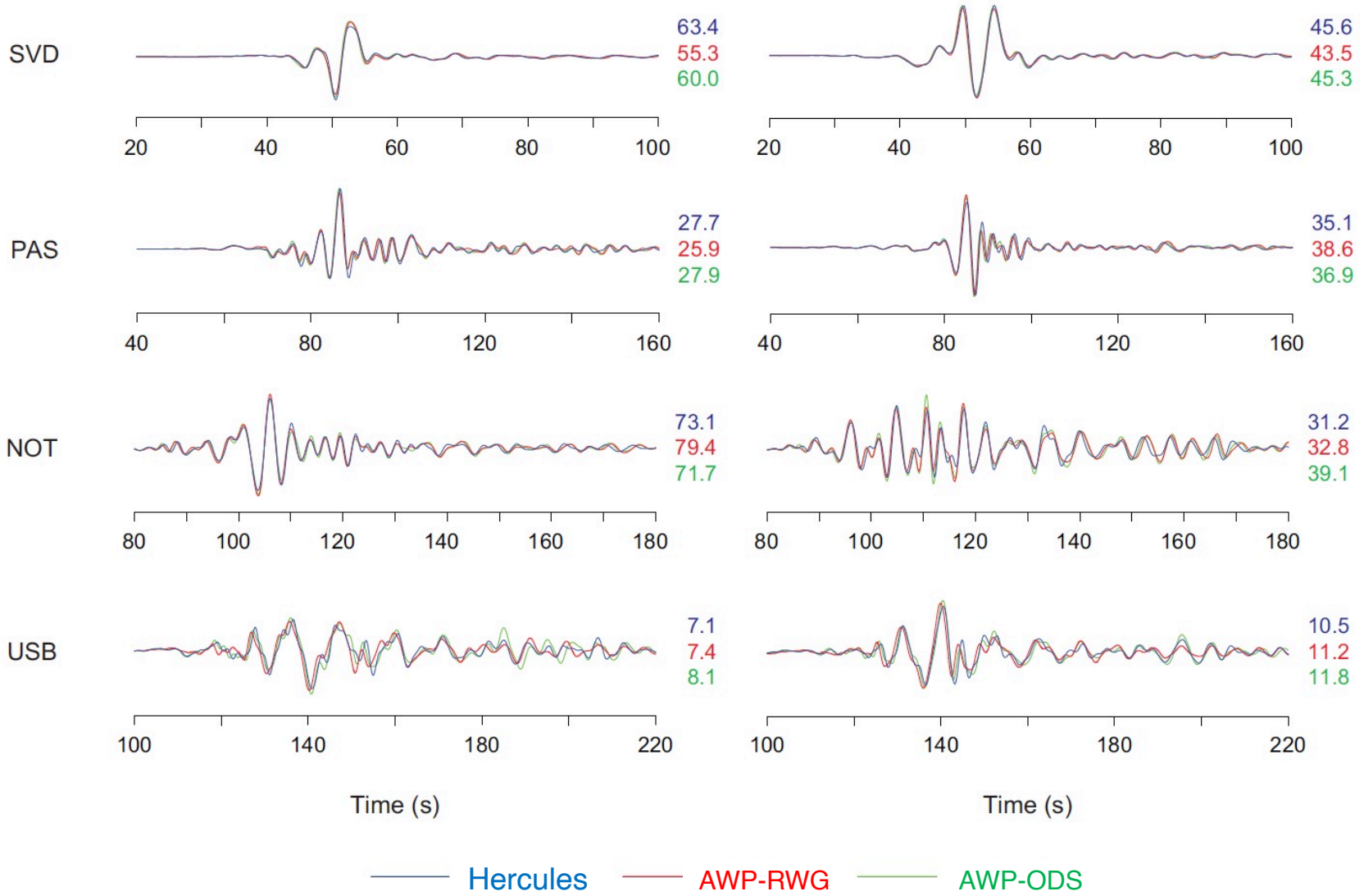


Bielak et al. (GJI, 2010)

Quantitative comparisons

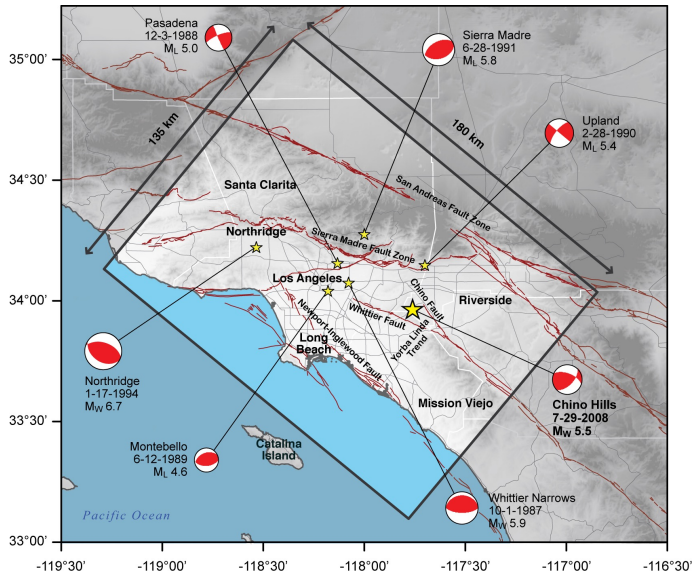
Goodness-of-fit (GOF) metrics

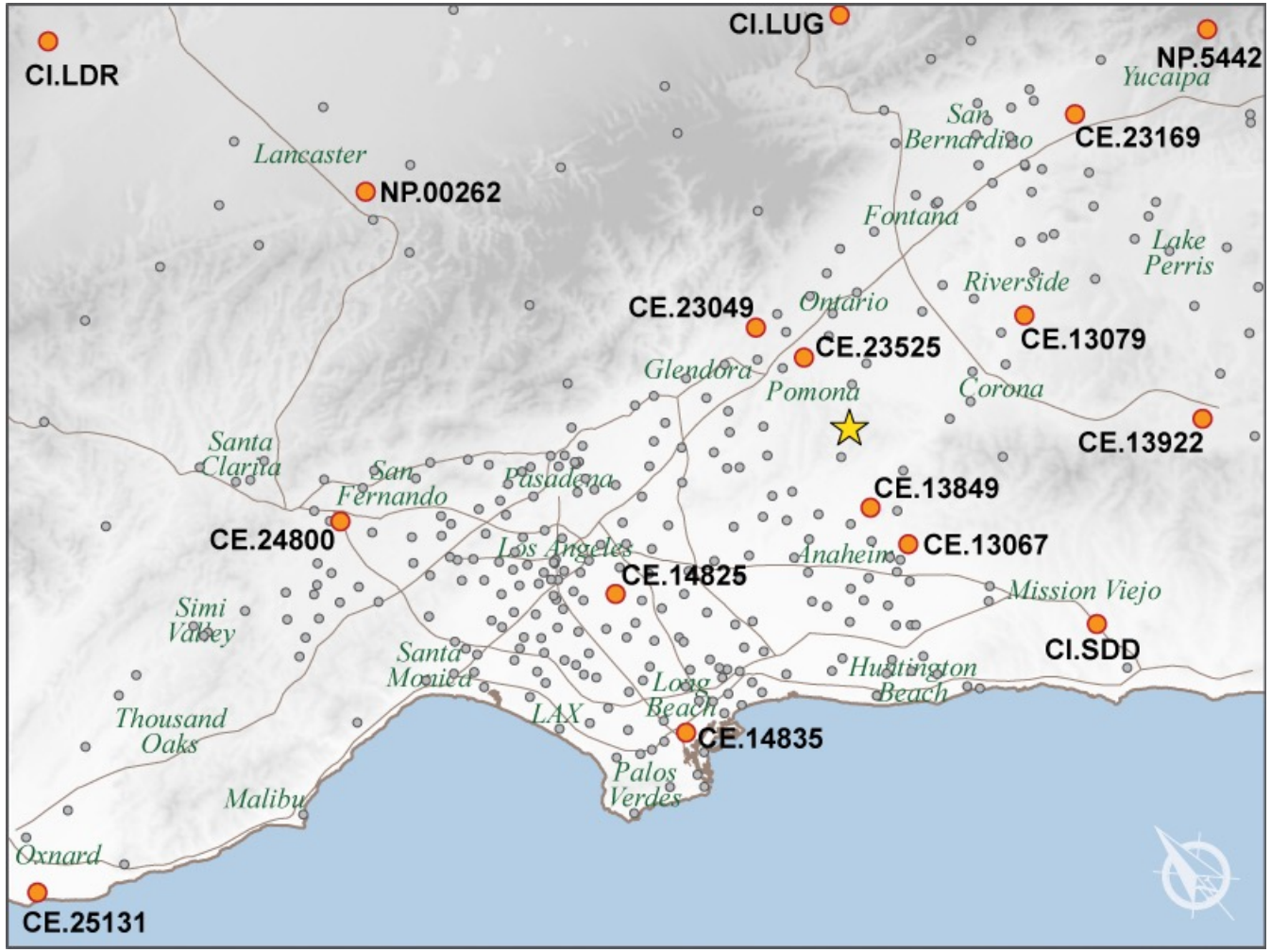
Cross Correlation	Arias Intensity	Energy Integral	Duration	8 – 10 Excellent
	PGA	PGV	PGD	6 – 8 Good
		Fourier Spectrum	Response Spectrum	4 – 6 Fair
				0 – 4 Poor

- Wiggle-by-wiggle
  - Kristekova et al. (2006, 2008)
- Signal metrics
  - Anderson (2004)
- Others

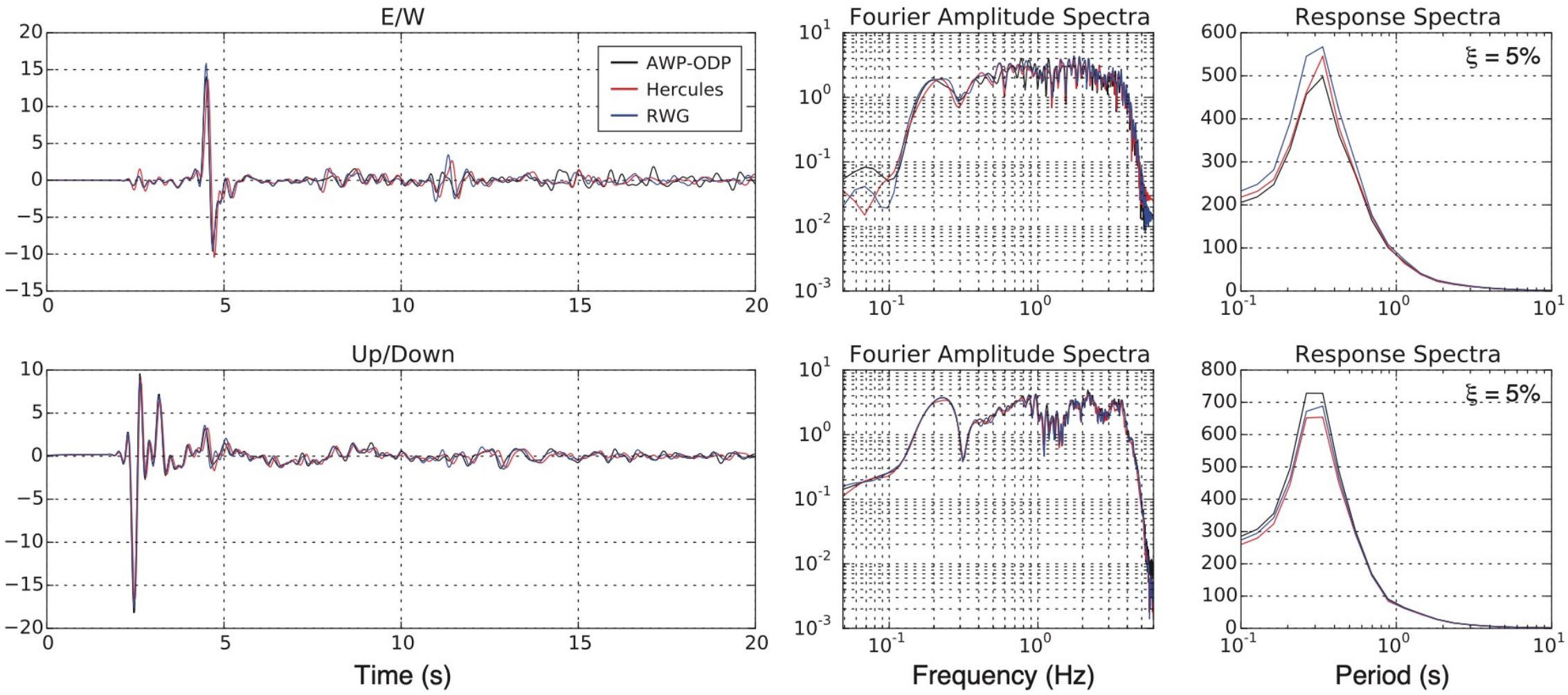
2008 Mw 5.4 Chino Hills earthquake verification and validation

- 4 Hz
- 200 m/s
- 300+ observations



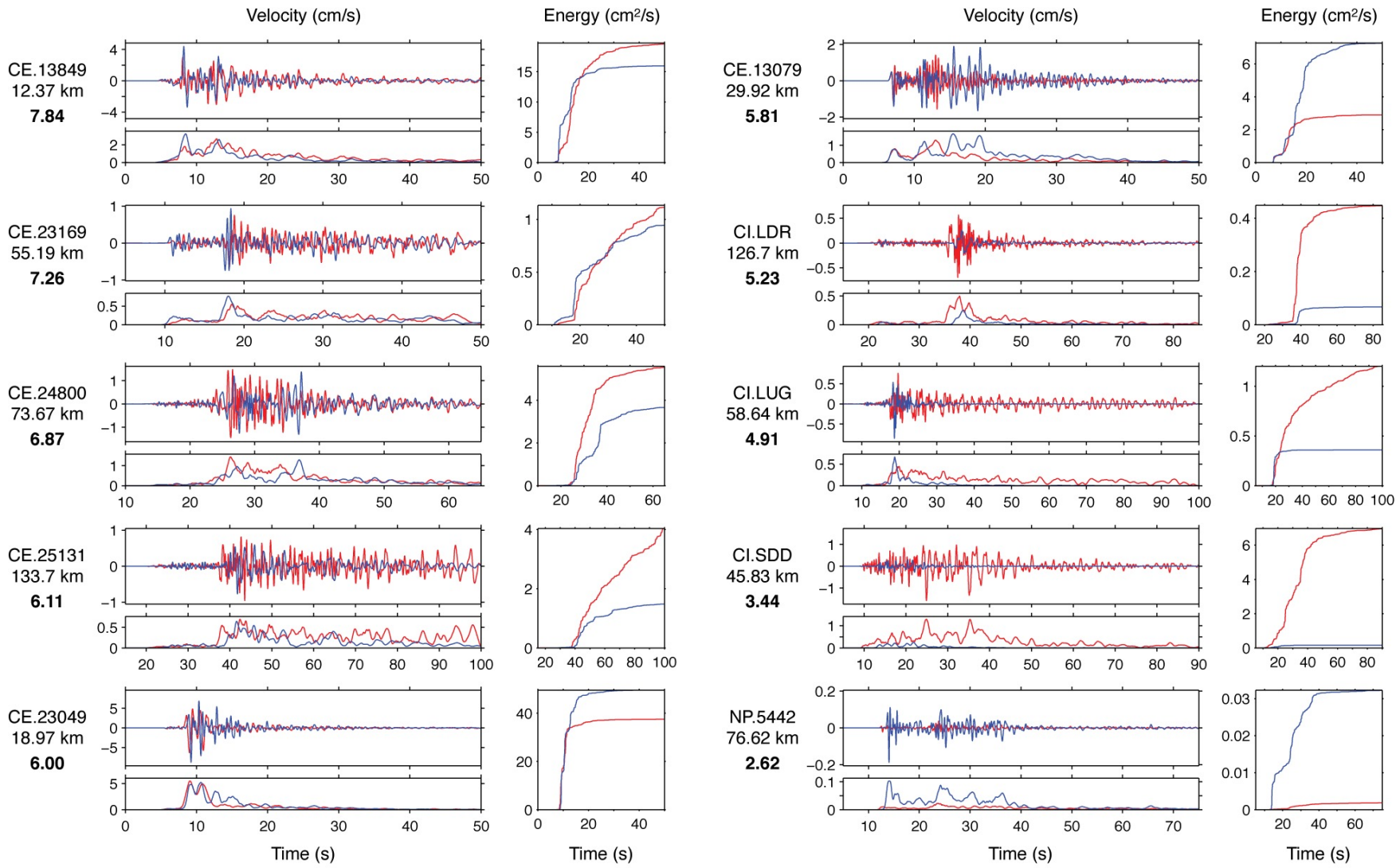


Verification at higher frequencies



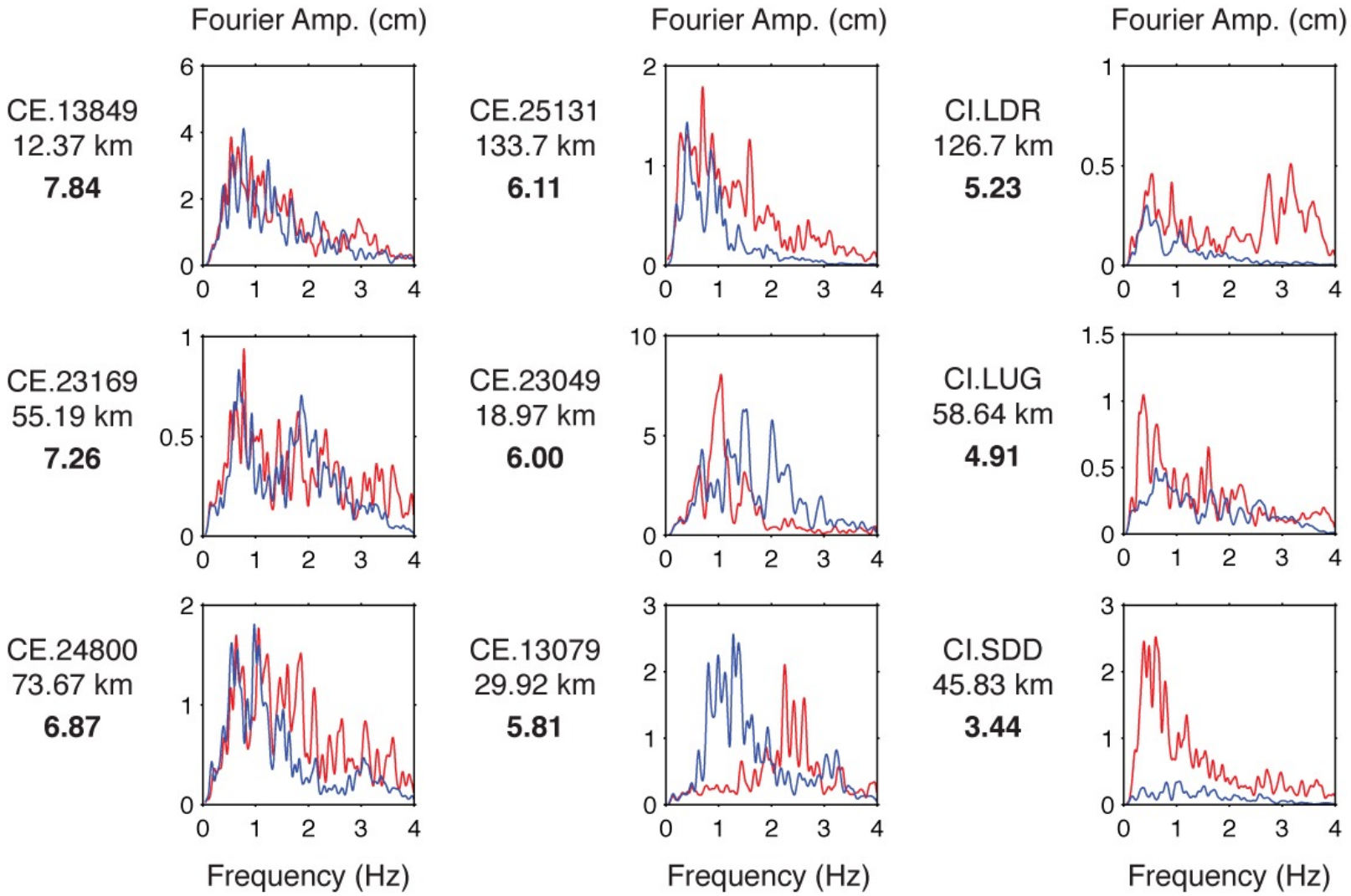
Taborda et al. (SCEC, 2016)

Validation: time series and energy integral



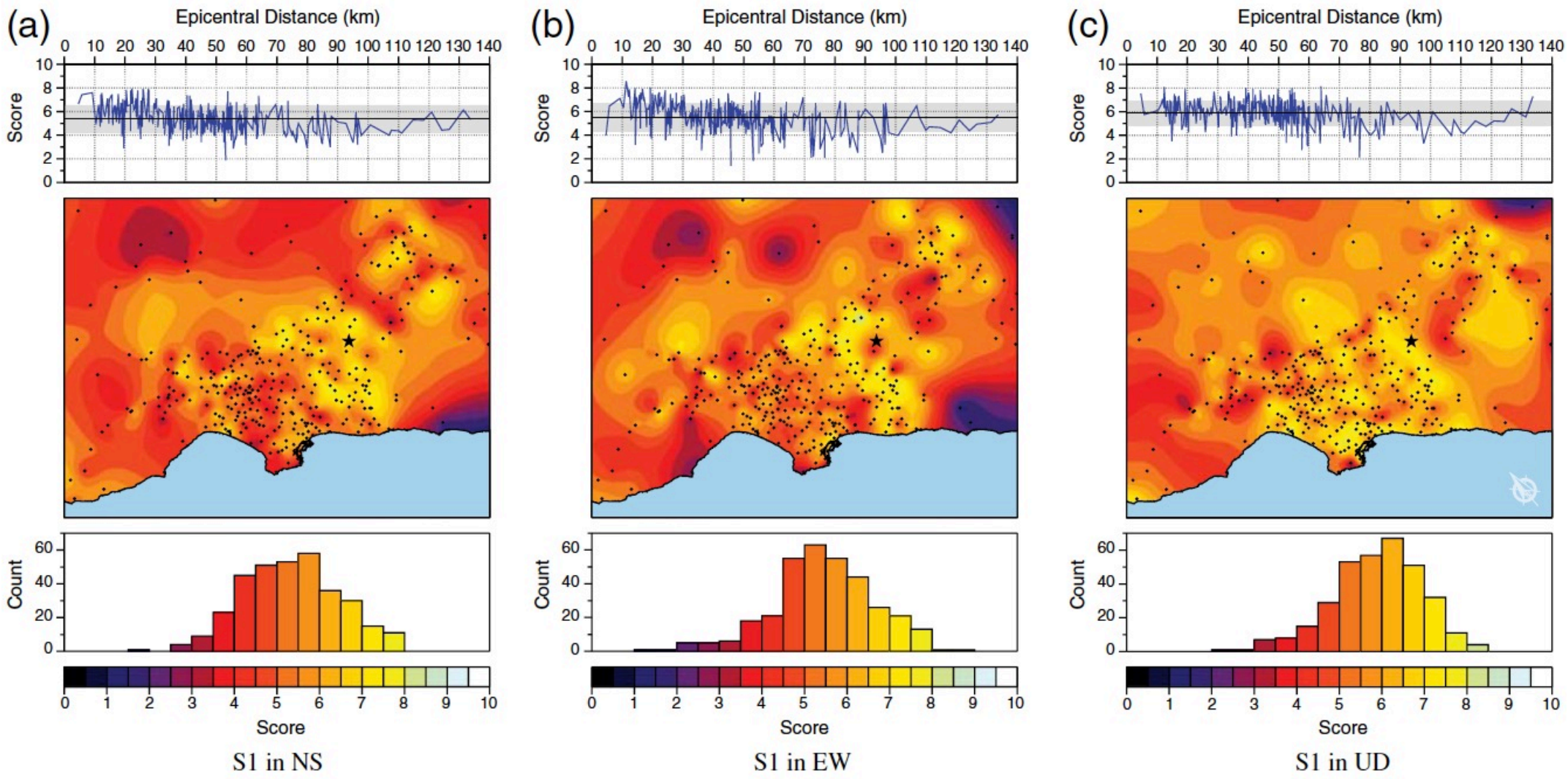
Taborda and Bielak (BSSA, 2013)

Validation: Fourier spectra



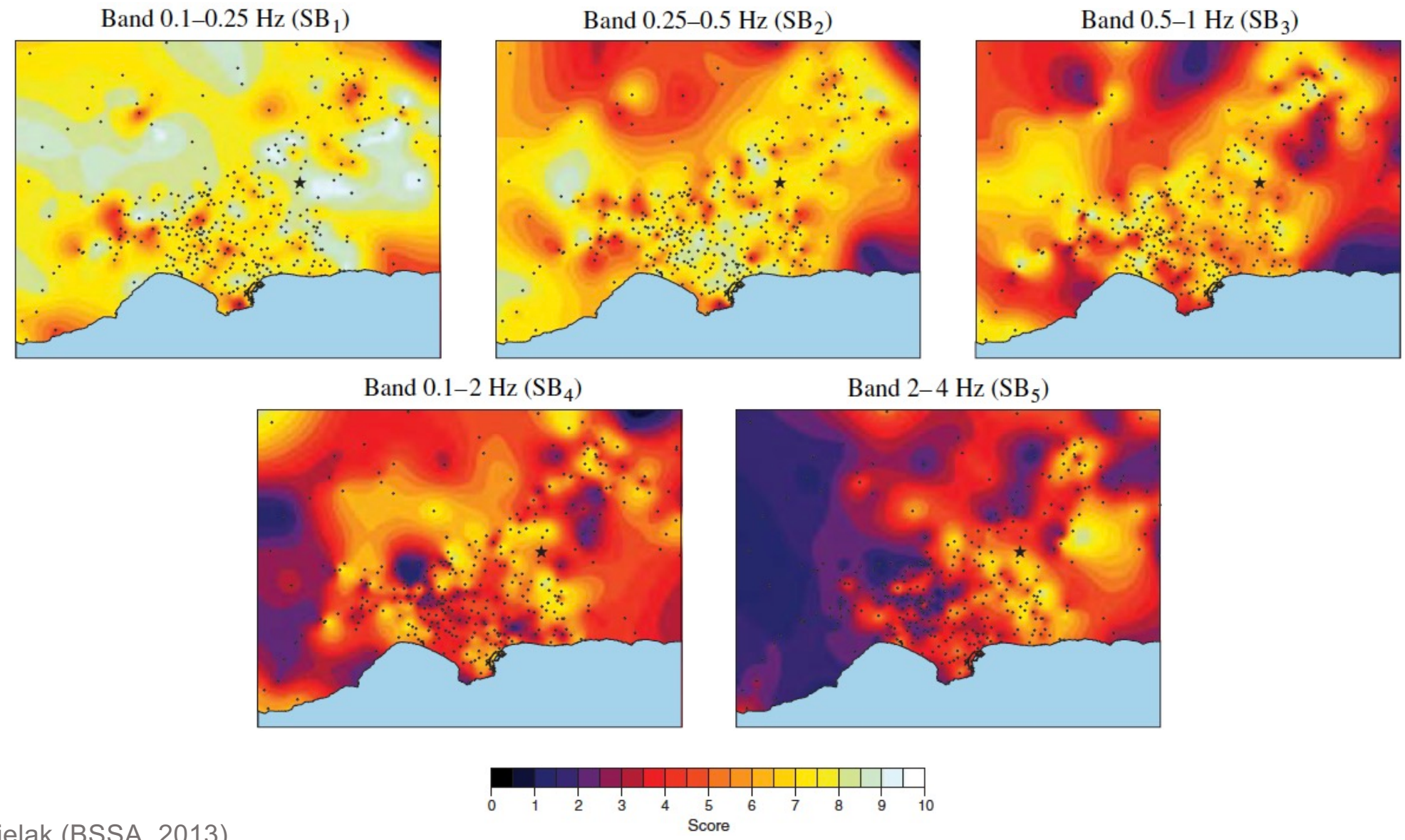
Taborda and Bielak (BSSA, 2013)

GOF maps (components of motion)



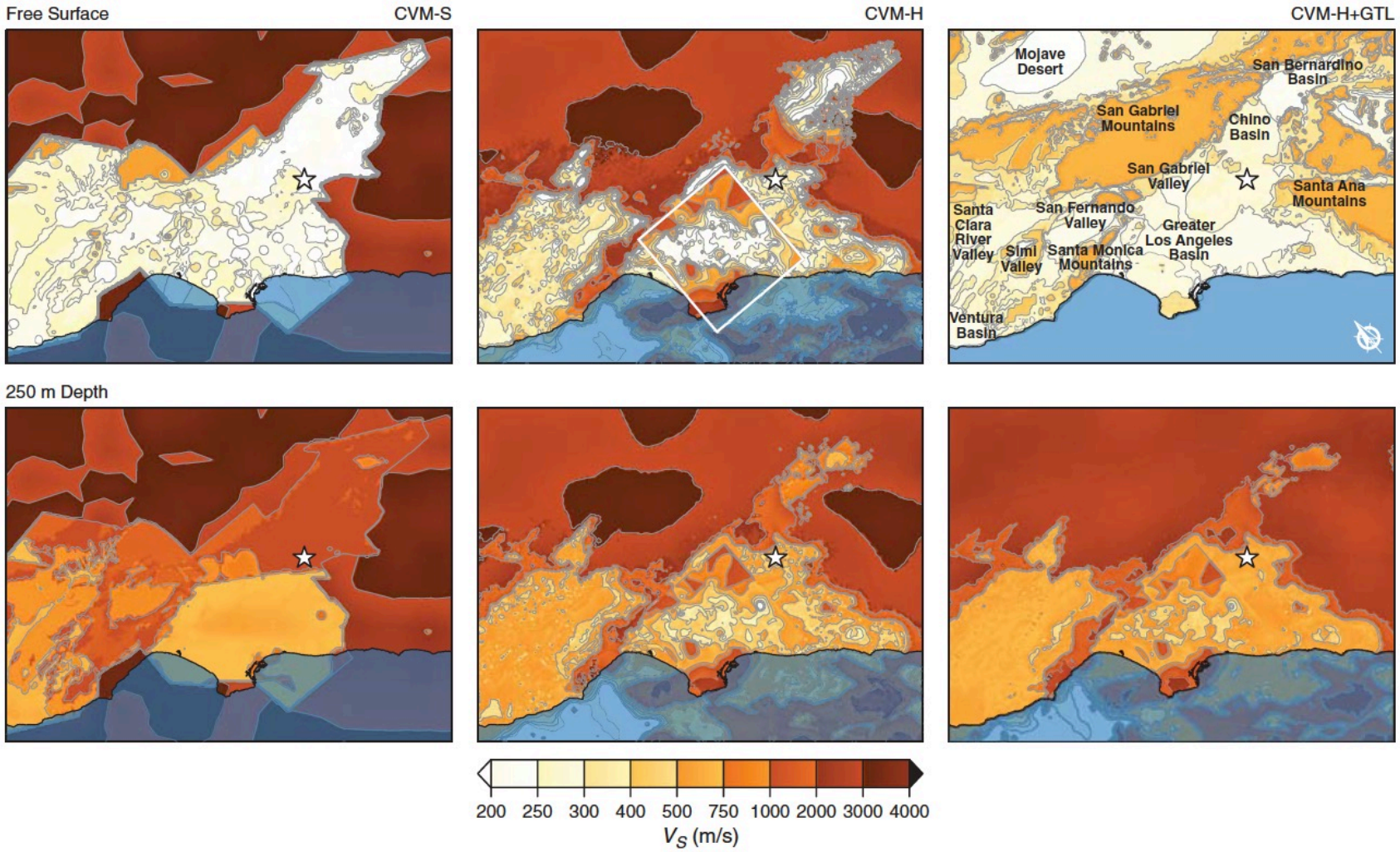
Taborda and Bielak (BSSA, 2013)

GOF maps (frequency bands)



Taborda and Bielak (BSSA, 2013)

Influence of seismic velocity models



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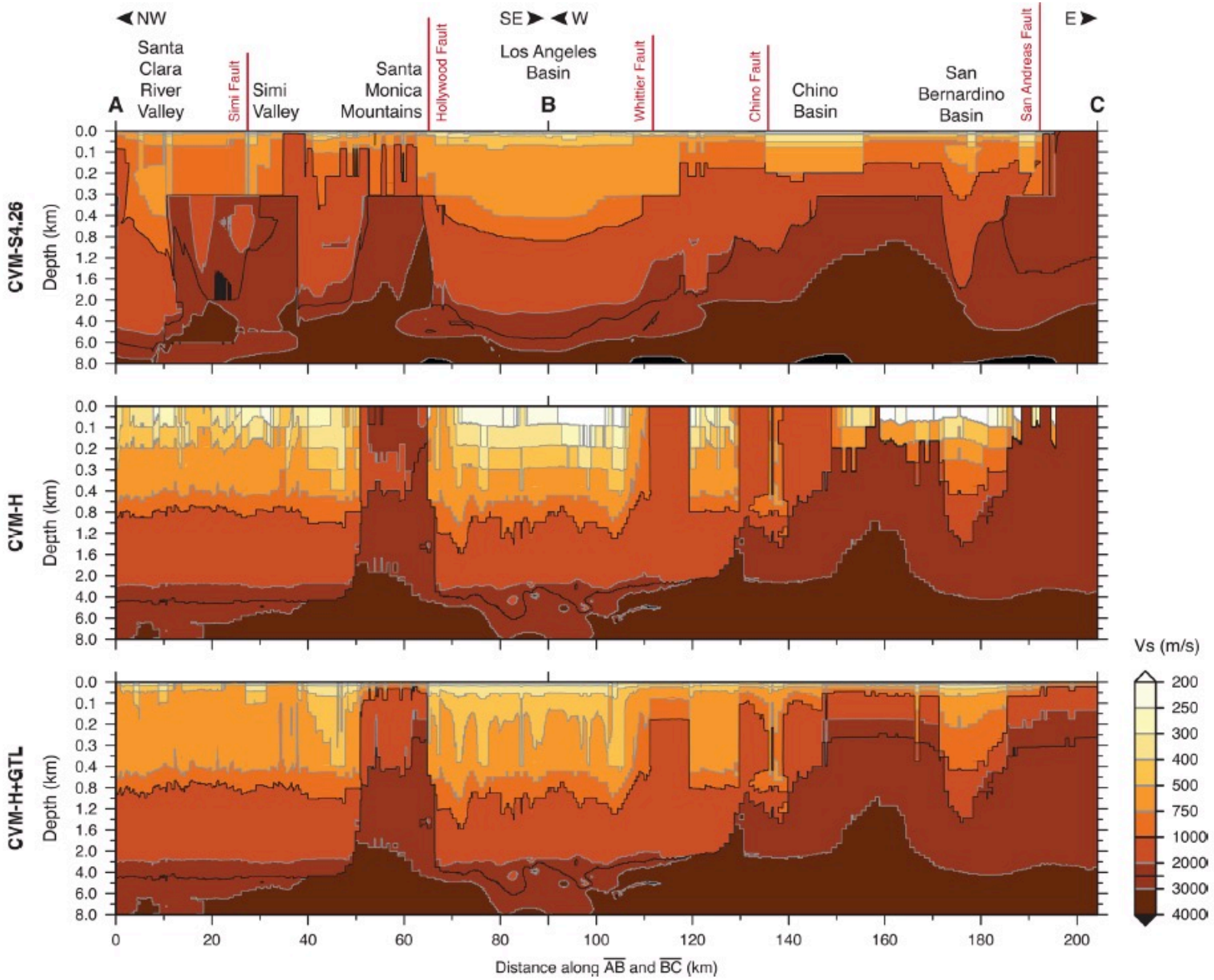
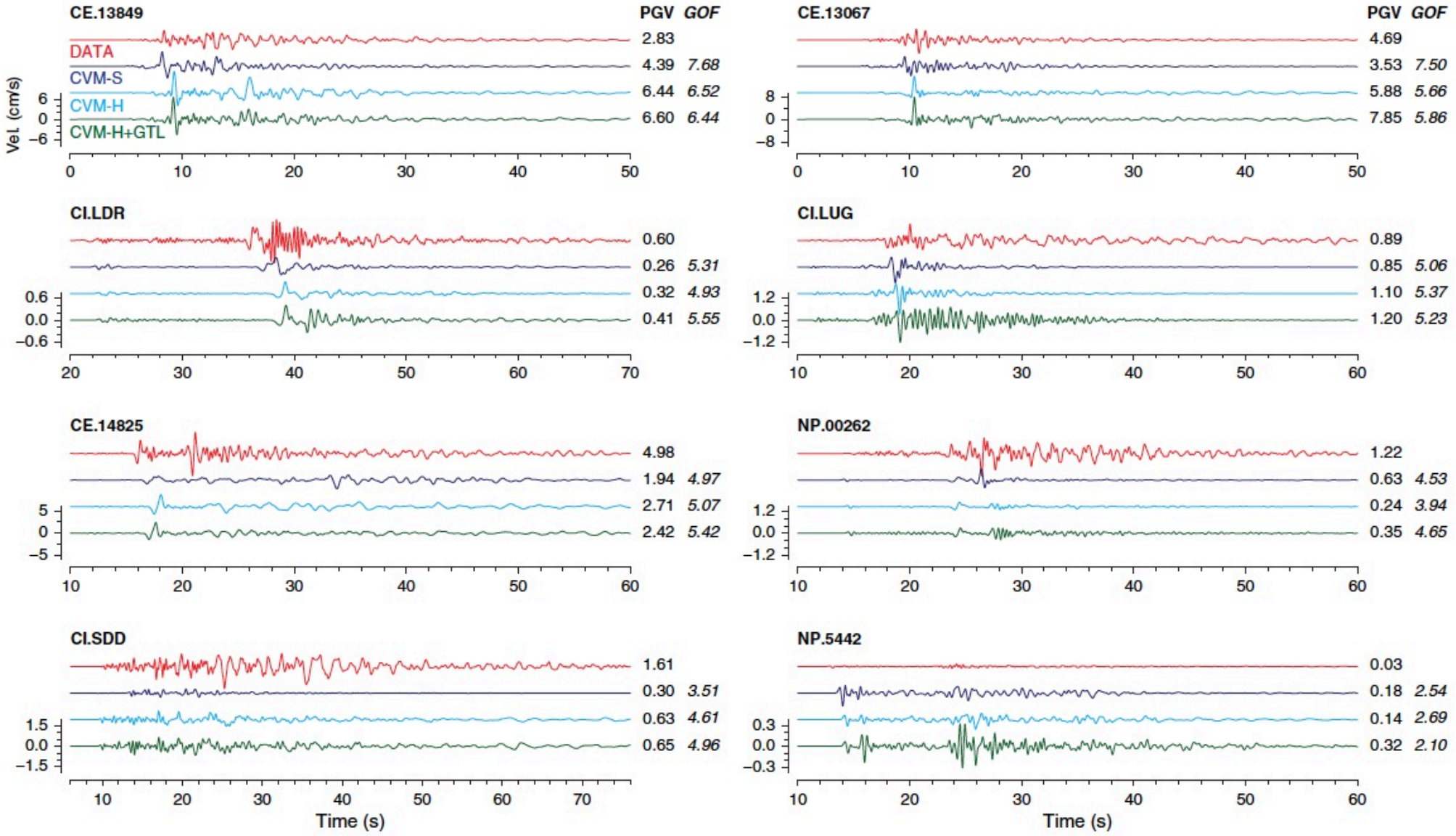


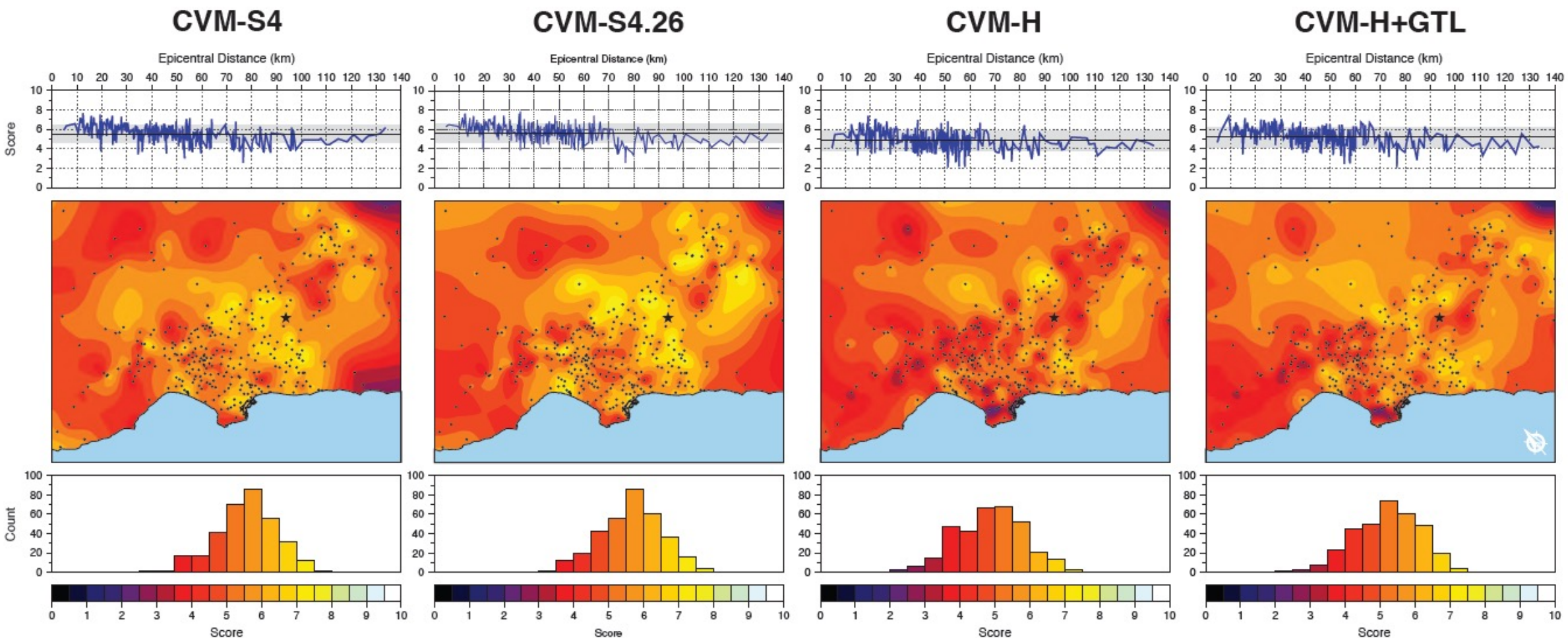
Taborda et al. (GJI, 2016)

Influence of seismic velocity models on synthetics



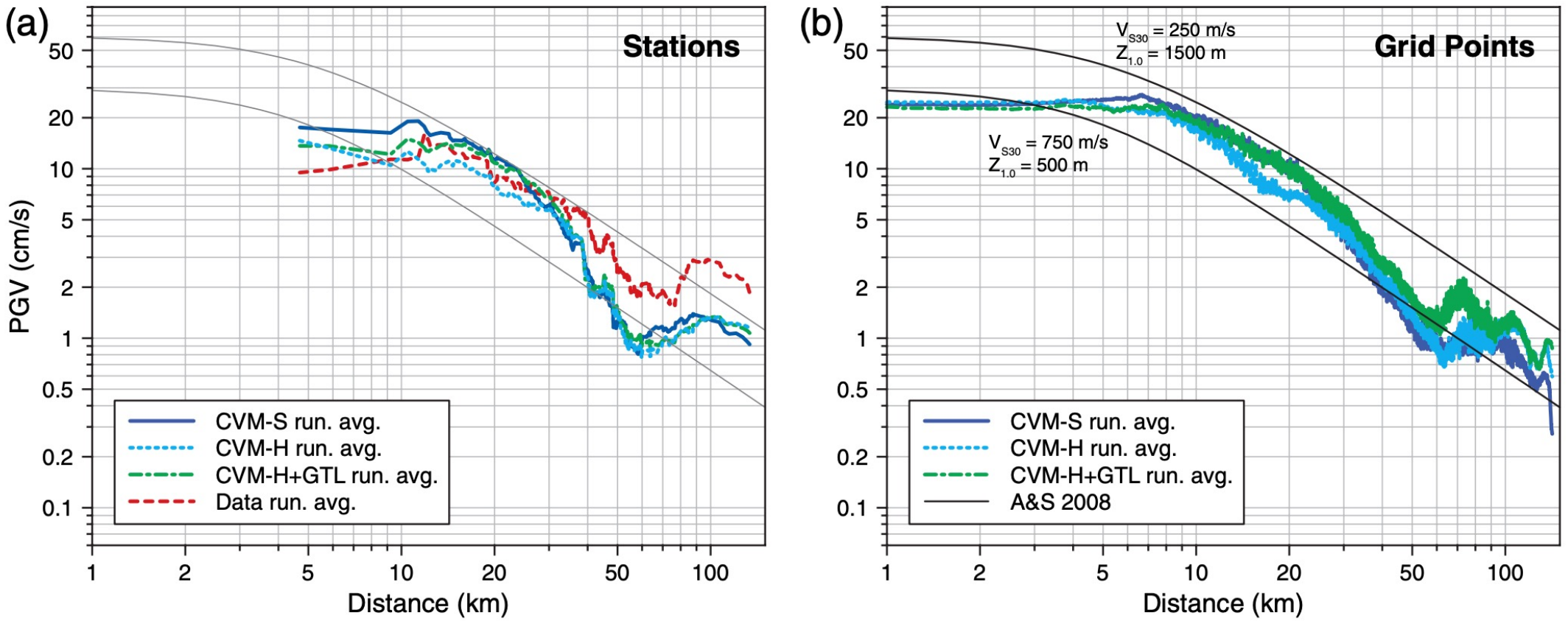
Taborda and Bielak (BSSA, 2014)

Influence of seismic velocity models on validation results



Taborda and Bielak (BSSA, 2014)

Validation in terms of attenuation



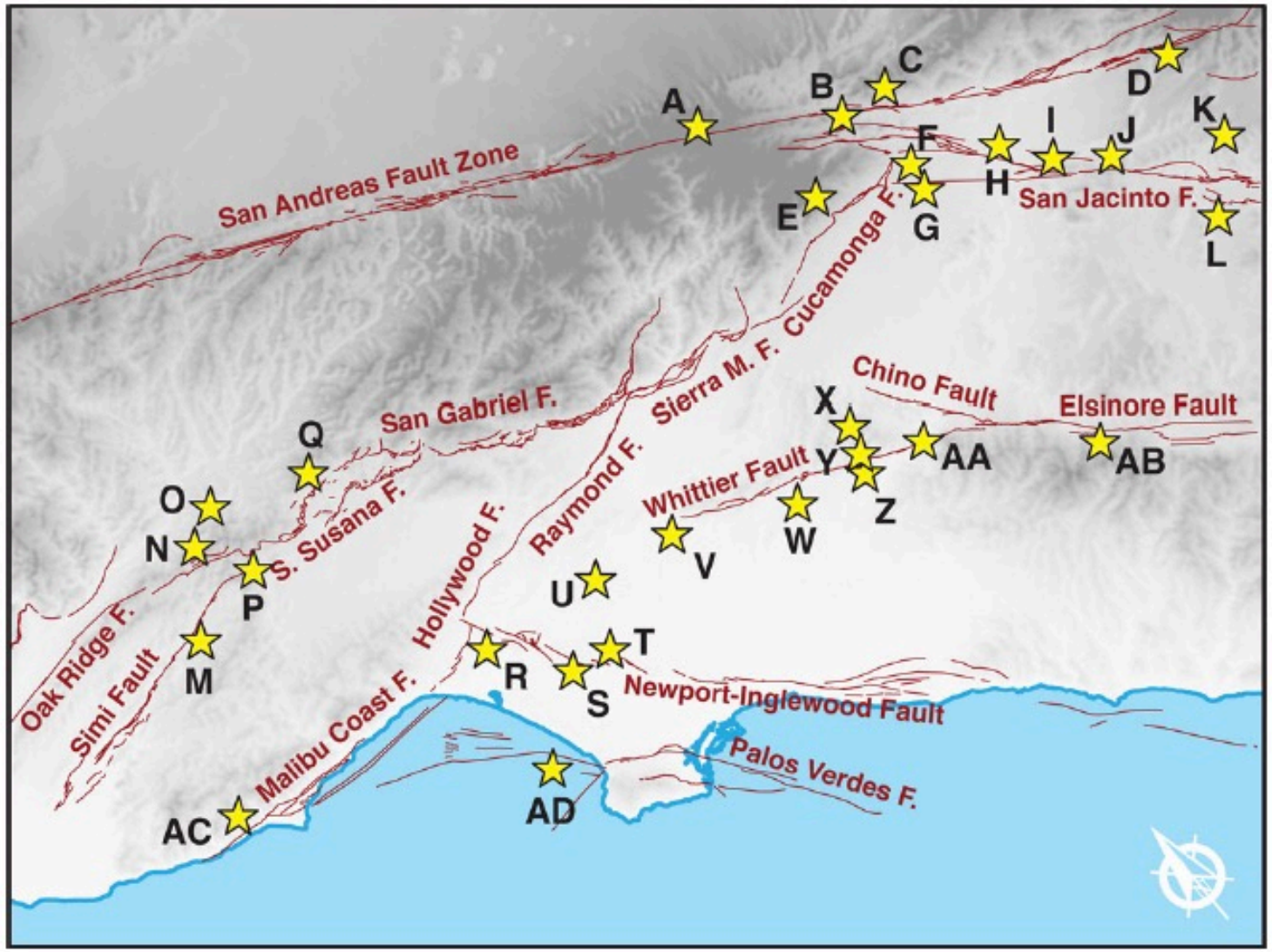
Taborda and Bielak (BSSA, 2014)

Validation as a means to evaluate velocity models

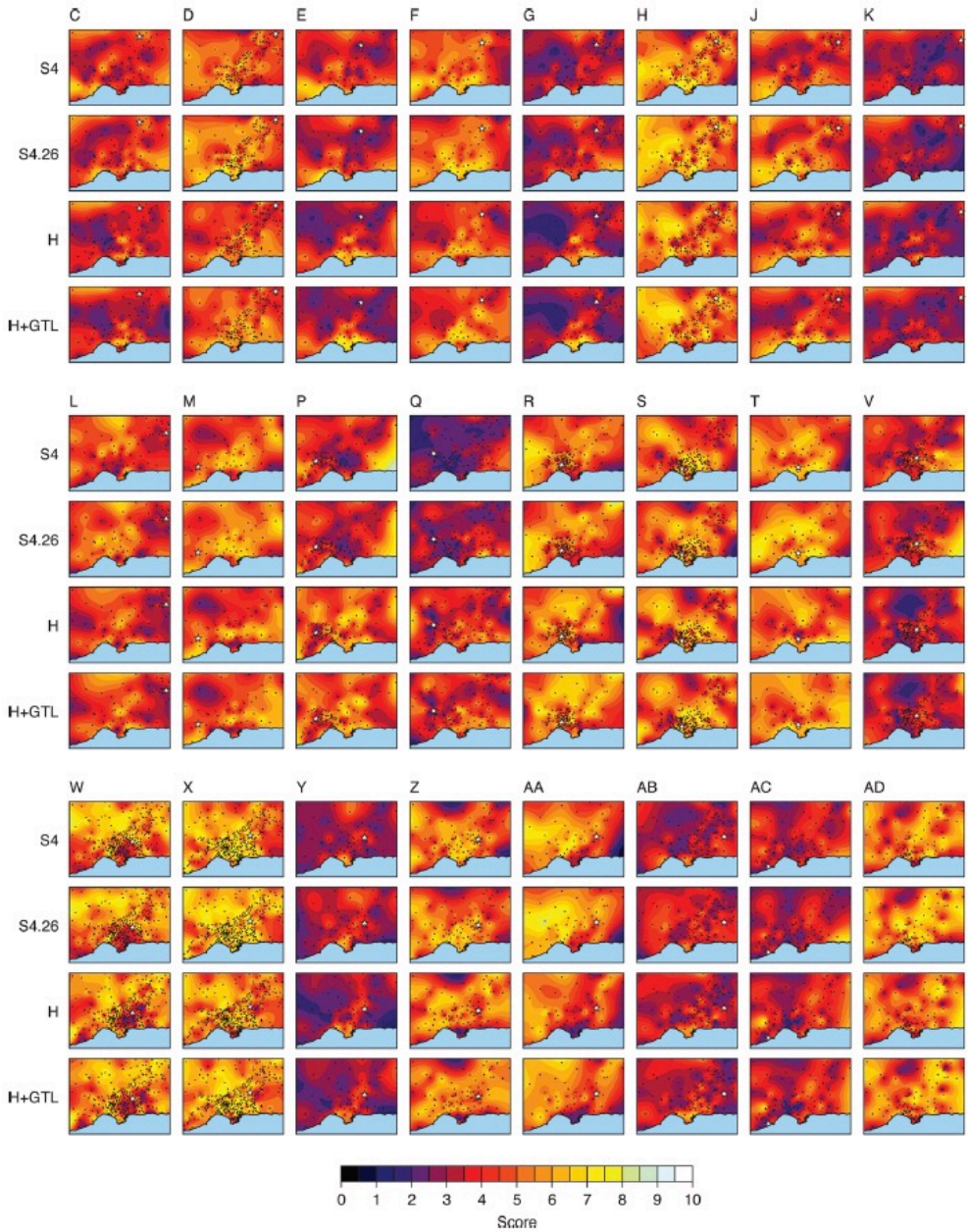
- 30 earthquakes
- 4 velocity models
- 1 Hz
- 200 m/s

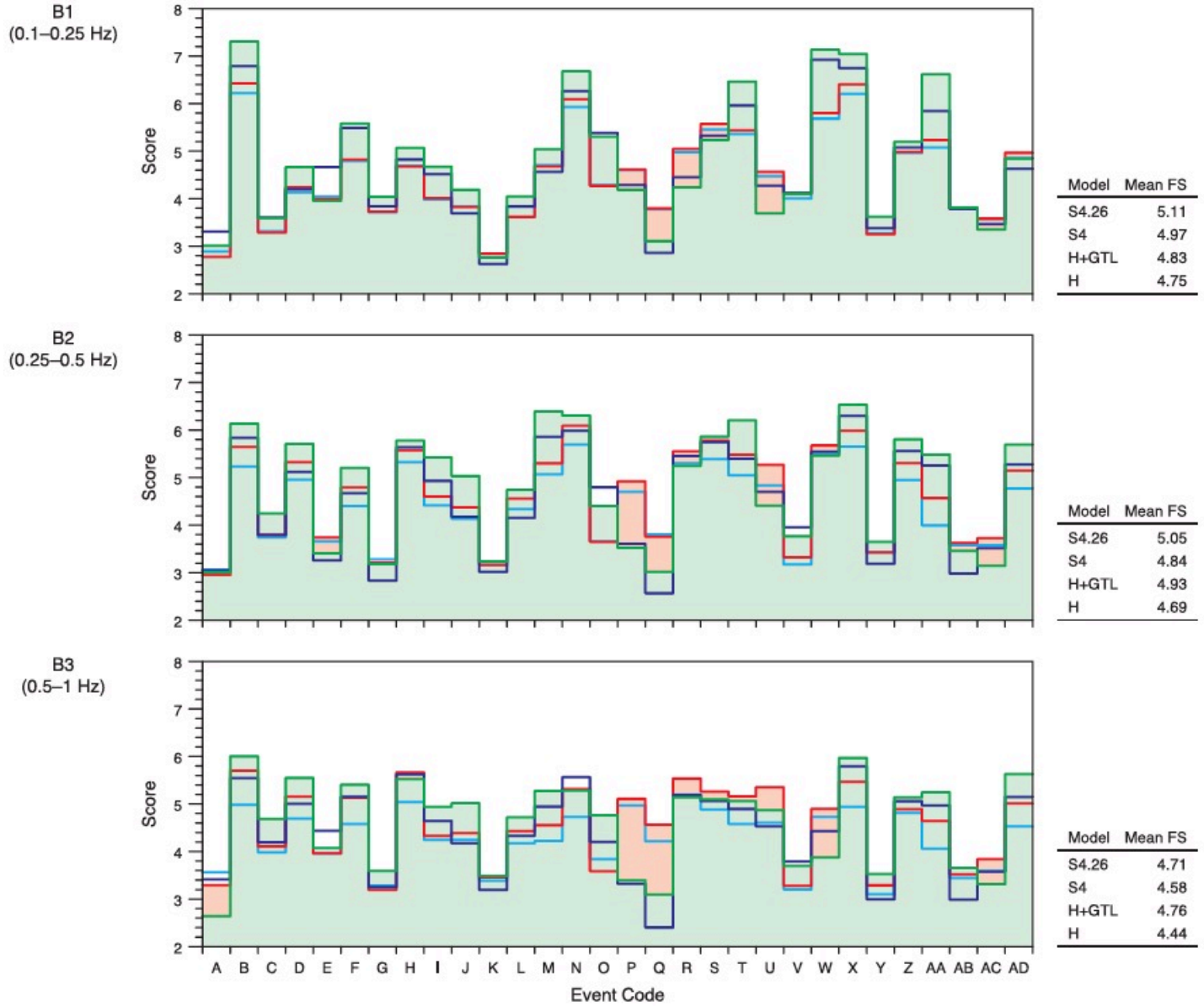
The caveat…

- Small-to-moderate magnitude events



Taborda et al. (GJI, 2016)





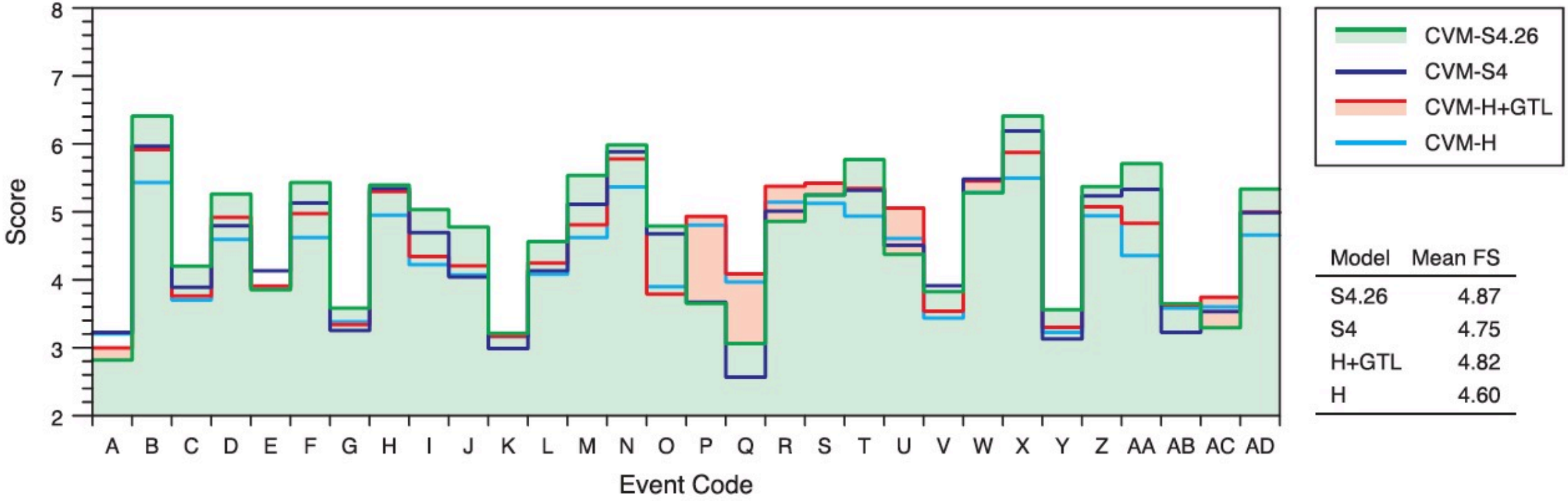
Model	Mean FS
S4.26	5.11
S4	4.97
H+GTL	4.83
H	4.75

Model	Mean FS
S4.26	5.05
S4	4.84
H+GTL	4.93
H	4.69

Model	Mean FS
S4.26	4.71
S4	4.58
H+GTL	4.76
H	4.44

Taborda et al. (GJI, 2016)

Synthesized results from validation



Model	Mean FS
S4.26	4.87
S4	4.75
H+GTL	4.82
H	4.60

Taborda et al. (GJI, 2016)

All that can be considered and how it matters

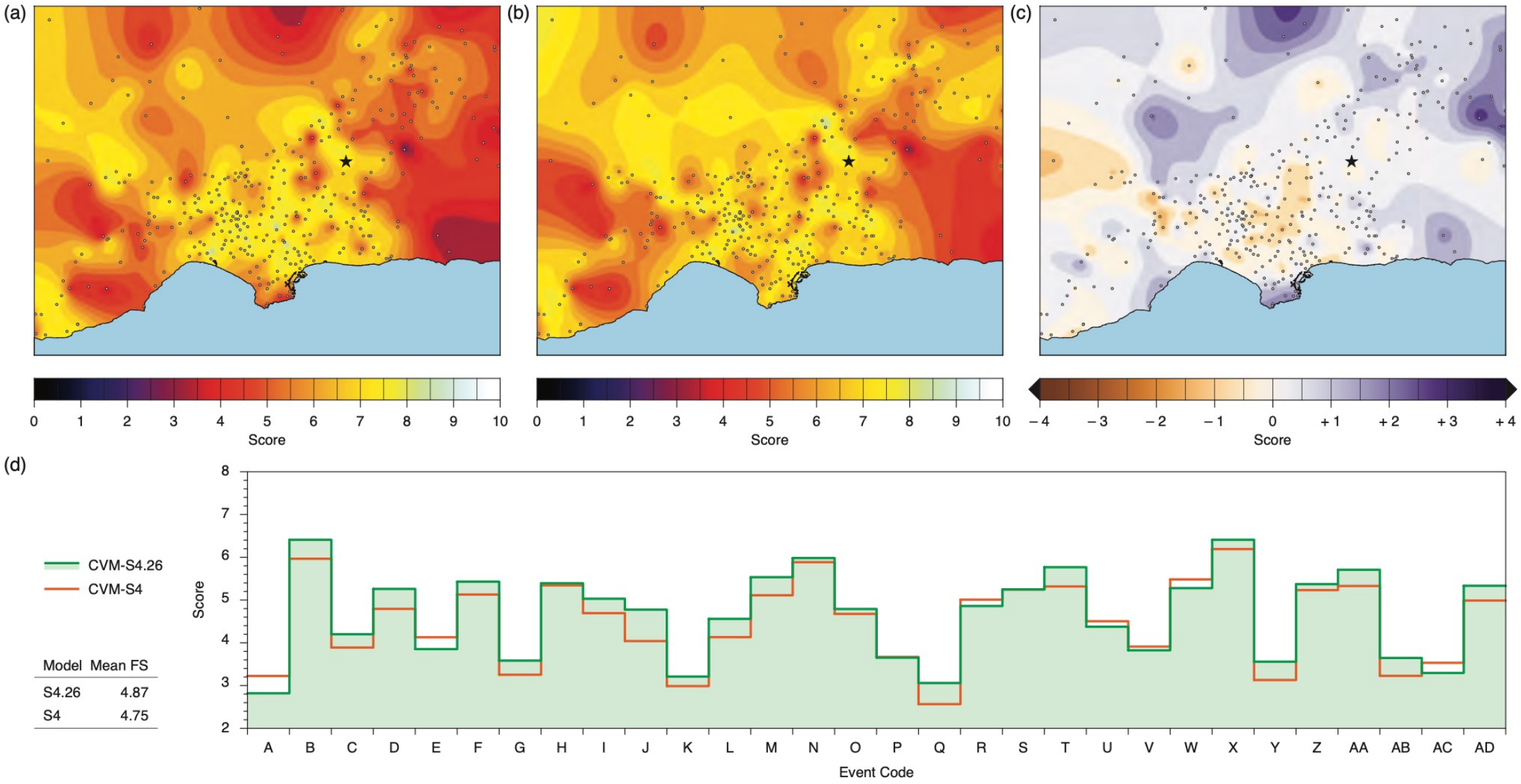
- Velocity model
- Minimum Vs
- Numerical resolution
- Attenuation model
- Source model
- Source uncertainty

Sim. ID	CVM-S		V_{Smin}		Pts. per wavelength		α in $Q_S = \alpha V_S$		λ in $Q(f) = Q_O f^{\lambda}$			Source		Magnitude		
	4	4.26	200	500	10	20	50	100	0 (a)	0 (b)	0.8 (b)	Point	Ext.	5.4	5.45	5.5
S1	•			•	•		•		•			•		•		
S2		•		•	•		•		•			•		•		
S3		•		•	•			•	•			•		•		
S4		•	•		•			•	•			•		•		
S5		•	•		•			•	•				•	•		
S6		•	•		•			•		•			•	•		
S7		•	•		•			•			•		•	•		
S8		•		•		•		•		•			•	•		
S9		•		•		•		•			•		•	•		
S10		•		•	•			•	•				•	•		
S11		•		•	•			•		•			•	•		
S12		•		•	•			•		•			•		•	
S13		•		•	•			•		•			•			•

(a) This corresponds to the attenuation model BKT2, which is frequency independent.
(b) This corresponds to the attenuation model BKT3, which can be frequency dependent if $\lambda \neq 0$.

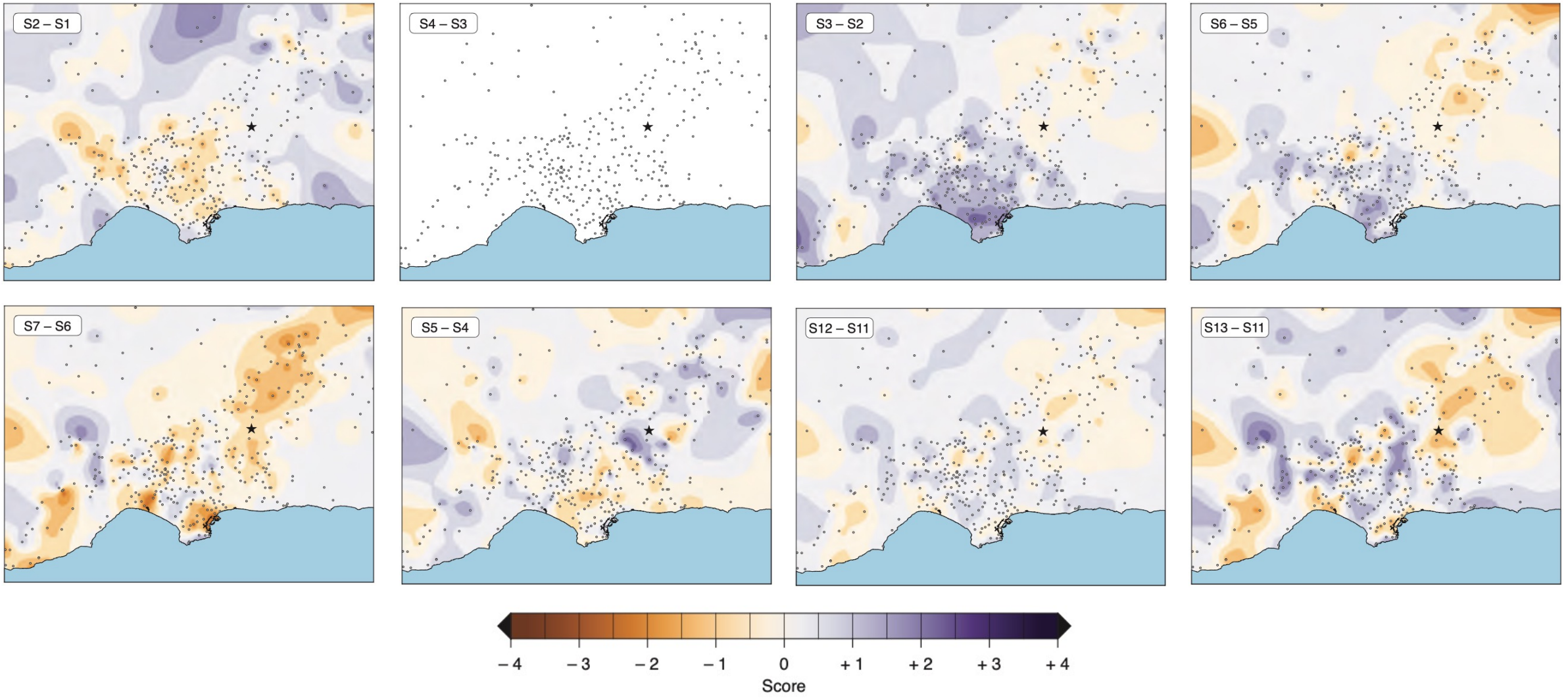
Taborda et al. (WCEE, 2017)

Various possible combinations (CVM here)



Taborda et al. (WCEE, 2017)

Various possible combinations (CVM, Attenuation, Source, …)



Taborda et al. (WCEE, 2017)

(Preliminary) concluding remarks

» Velocity model	Matters a lot – perhaps the most.
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» Source model	Matters more than one would think of. Even for small earthquakes. Even at some distance (low vs high frequencies, near vs far field.)
» Source uncertainty	Can make a significant difference.

Some other aspects of interest

» Workflows for automated work and combination of methods

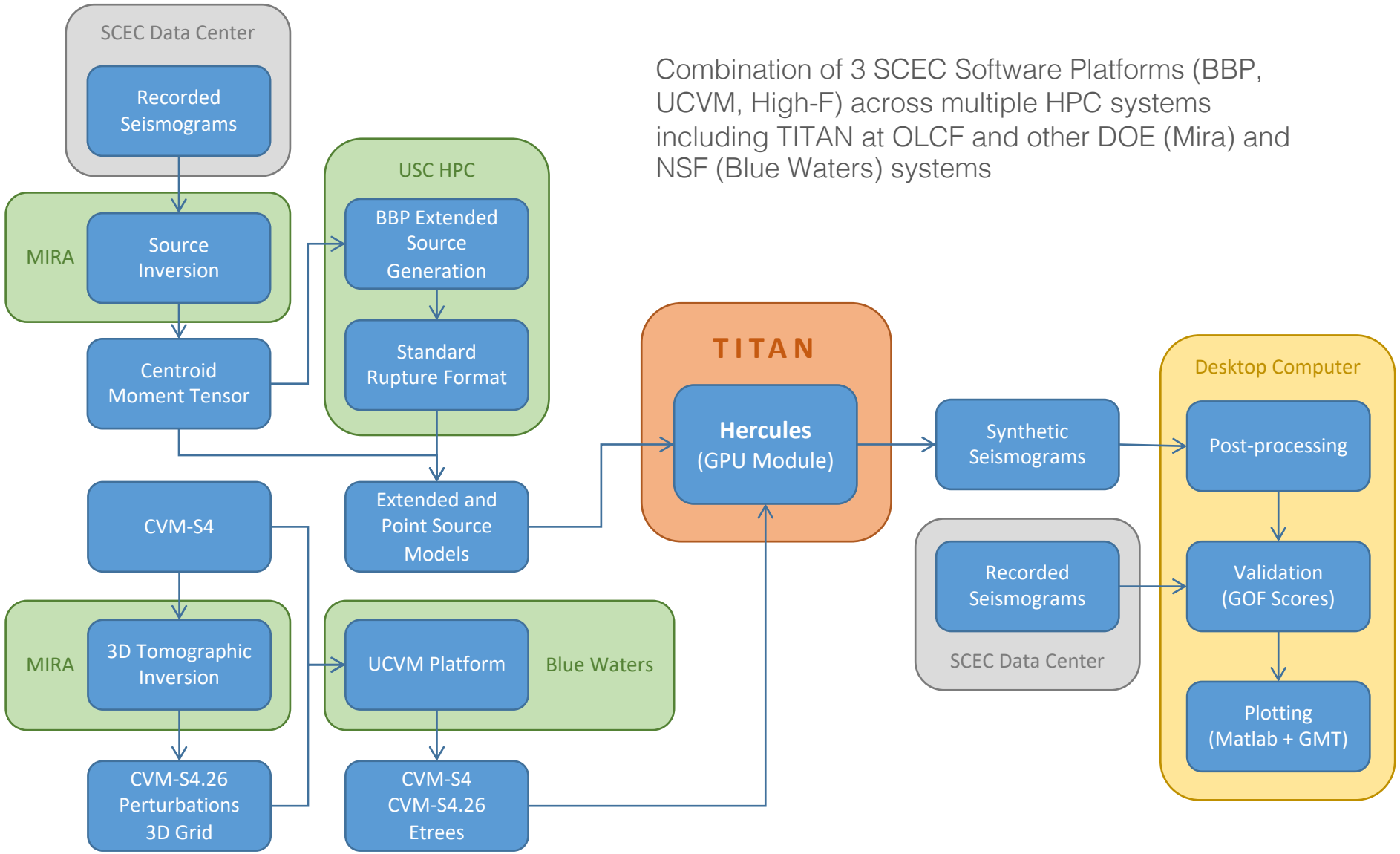
» Focus on measures that matter most

» Influence of the urban environment

» Nonlinear site-effects

» Topography

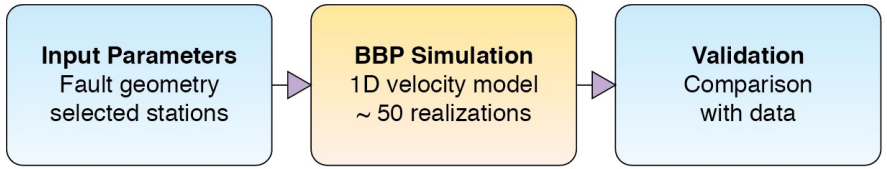
Integrating Simulation Platforms for Automated Validation



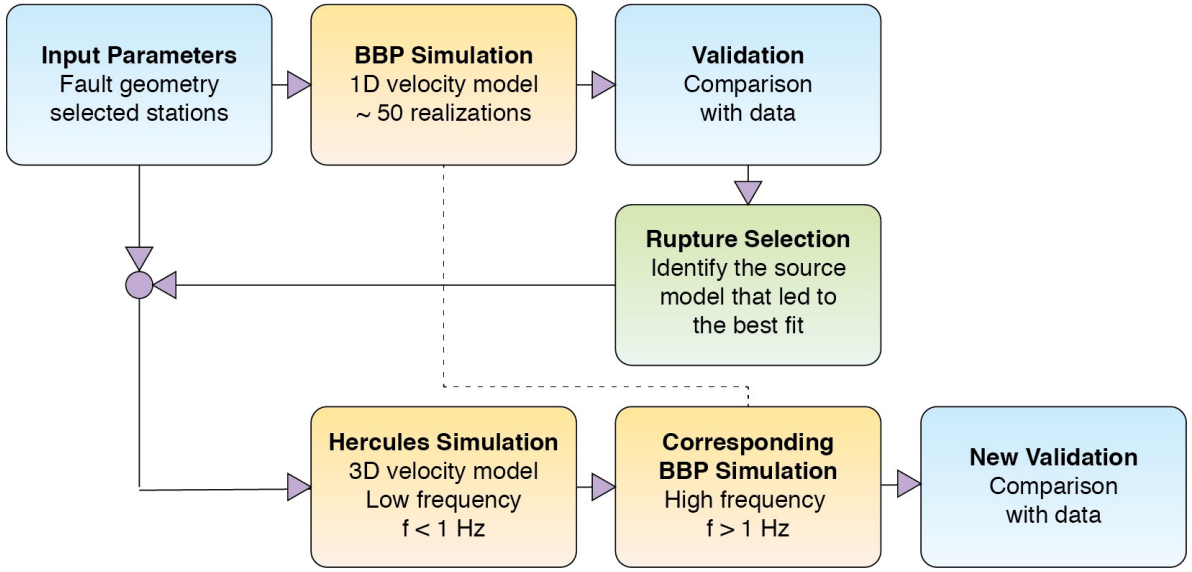
Combination of 3 SCEC Software Platforms (BBP, UCVM, High-F) across multiple HPC systems including TITAN at OLCF and other DOE (Mira) and NSF (Blue Waters) systems

Integrating 1D BBP and 3D Simulations

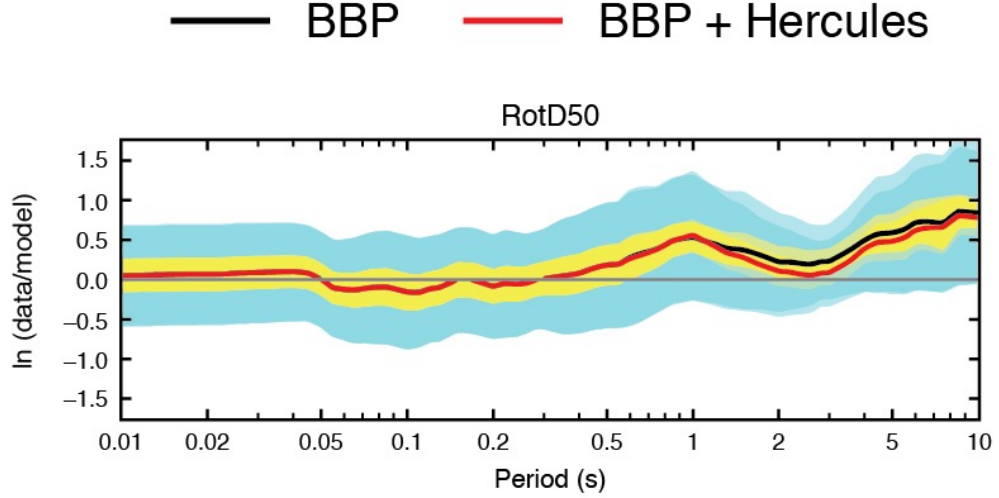
Original Workflow



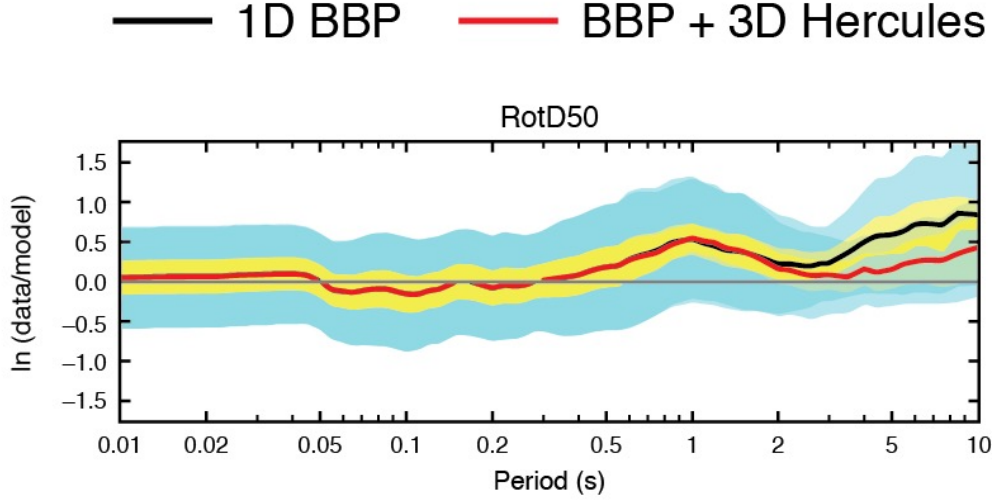
Modified Workflow



1D Models Comparison

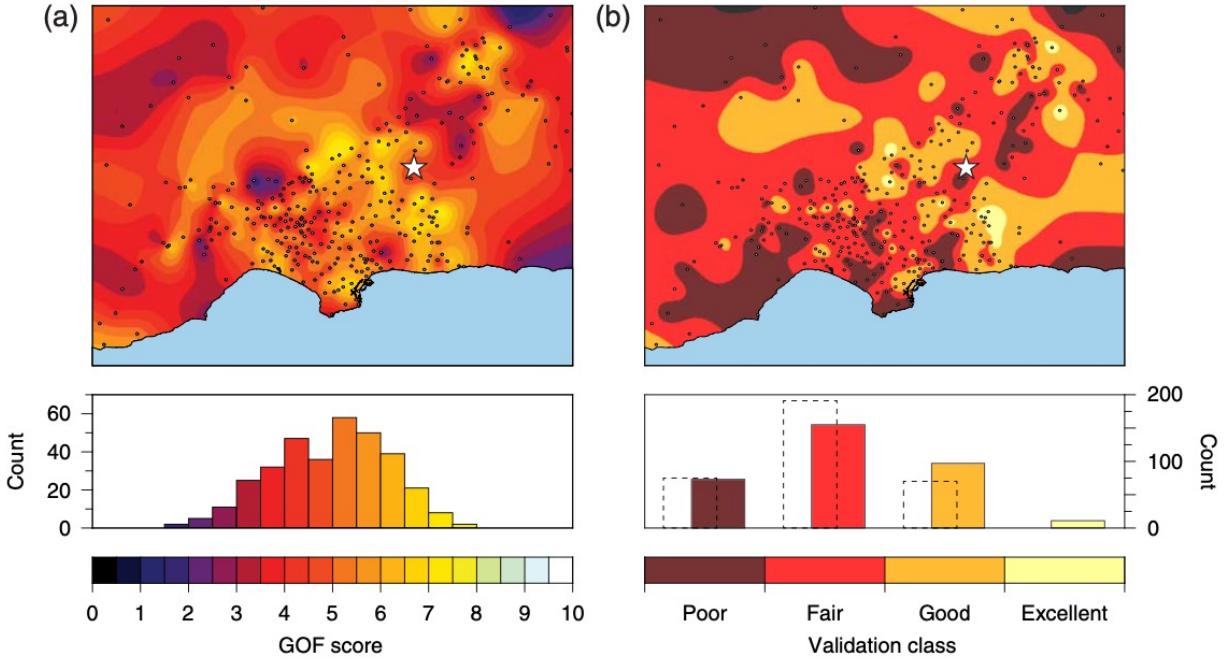


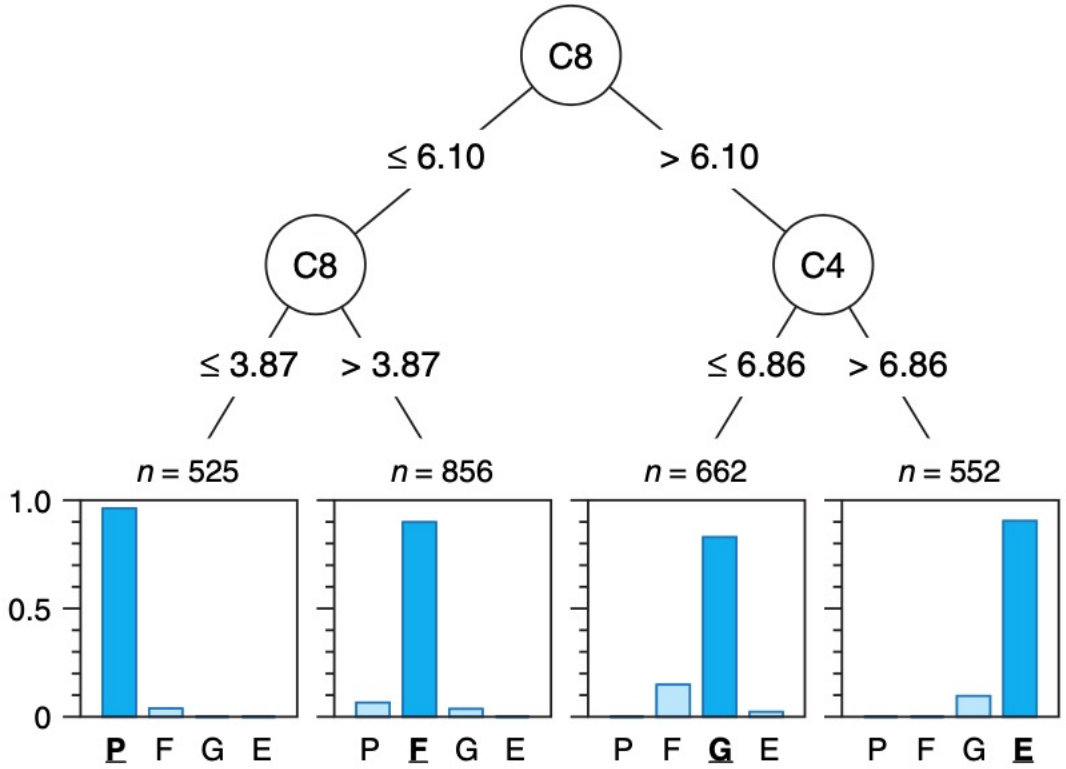
3D Improvement



Taborda et al. (SCEC, 2014)

Alternatives to reduce validation post-processing



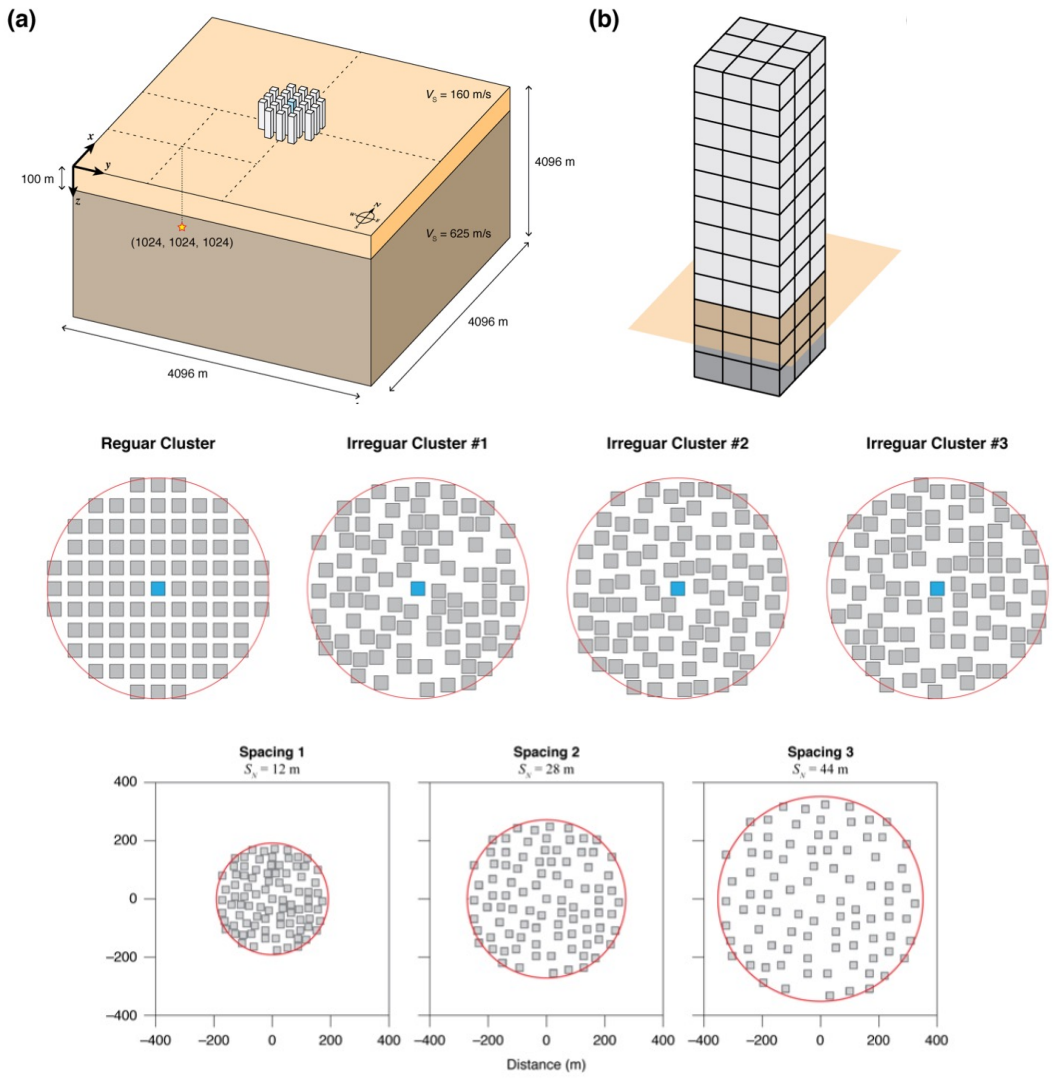


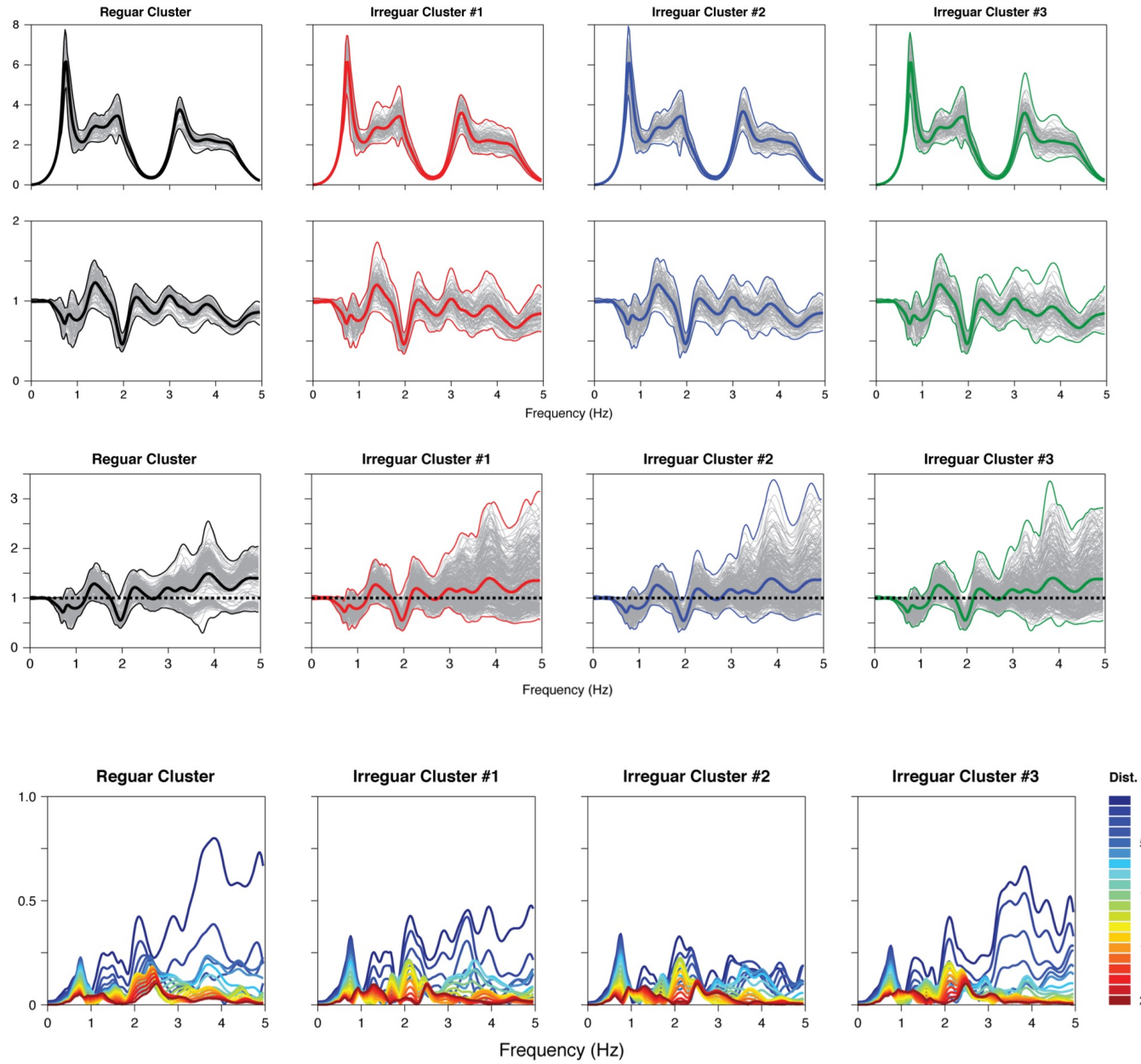
» C8: Response spectra

» C4: Energy

Khoshnevis and Taborda (BSSA, 2018)

Attempts to understand effects of urban environments





Taborda and Isbiliroglu (USGS, 2018)

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» Source uncertainty	Can make a significant difference.
» Nonlinear soil	Matter a lot. Mostly local. But it may impact regional response to an extent we do not fully understand for now.
» Topography	We know it matters but cannot fully characterize it for synthesis at regional scale just yet.
» Site-city interaction	We do not fully understand yet.

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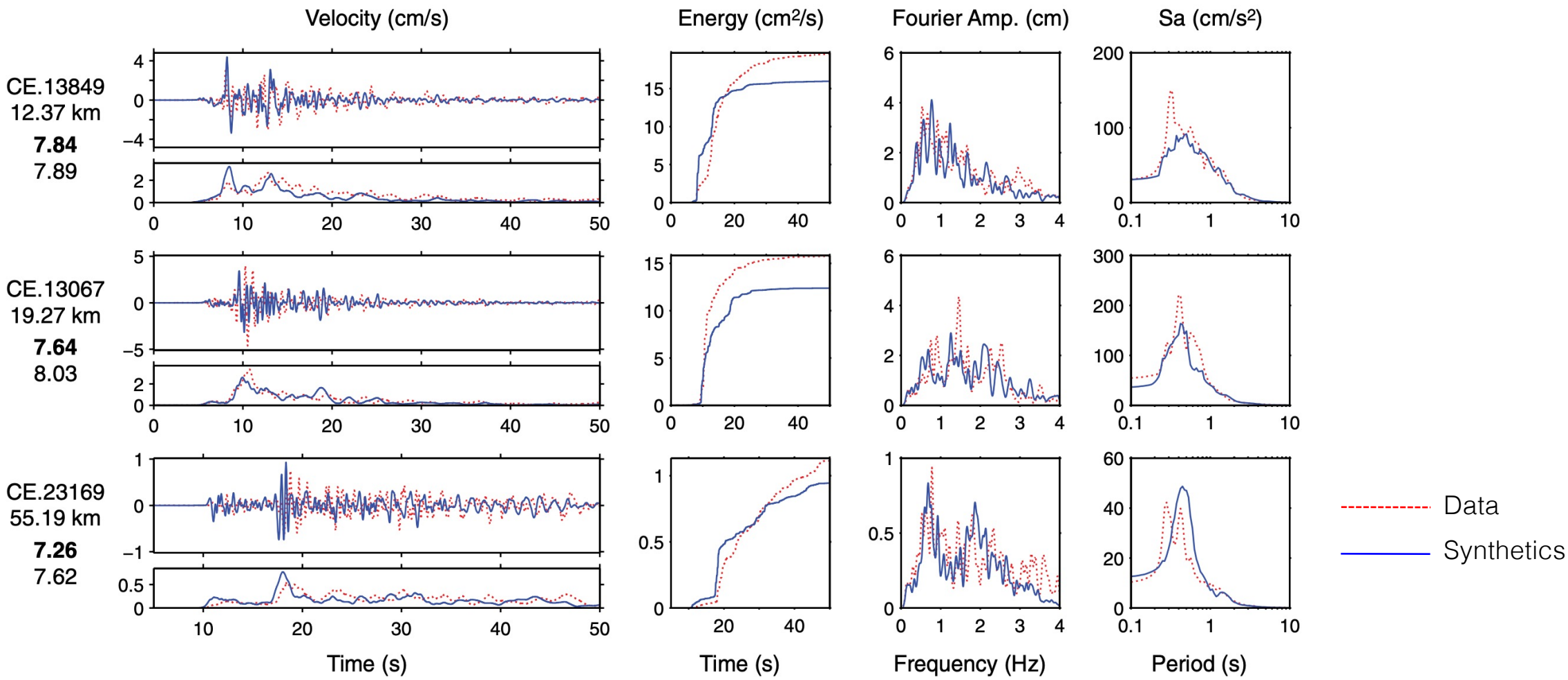
Under optimal conditions…



Taborda and Bielak (BSSA, 2013)

Some suggestions

- » Inversions: For better velocity models, thus other information.
- » Energy losses: Anelasticity and nonlinearities of engineering interest.
- » Variability: Anything that increases it matters at higher frequency (e.g., topography).
- » Uncertainty: Simulations / workflows that can carry forward information about uncertainty.
- » Workflows: In the form of automated simulations that can be repeated systematically.

Thank you

The people behind…

The agencies and programs that made it possible…