Simulazioni basate sul metodo 1D-FK deterministico per i terremoti dell’Appennino centrale

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REGIONAL-SCALE EARTHQUAKE **GROUND MOTION PREDICTIONS** THROUGH PYHSICS-BASED AND EMPIRICAL APPROACHES: **A CASE STUDY CENTRAL ITALY**

MOTIVATION

- Accurate broadband ground motion simulations are essential for conducting realistic hazard analyses.
- The number of ground motion records from strong earthquakes in near-source conditions is limited: precise ground motion predictions through standard ground motion modeling (GMMs) may not be satisfactory.
- Deterministic near-source broadband ground motion predictions can be performed when information about the earthquake rupture and the propagation of seismic waves through the Earth are available.
- Employing simulation techniques characterized by accuracy and computational efficiency is important for near-real-time hazard evaluation.
- The most precise simulation methods rely on 3D wave propagation modeling. However, they are more costly than methods employing 1D wave propagation.

OBJECTIVE

- A key aspect of our analysis is determining the primary differences between 3D and FK-GFs-based 1D simulation for The August 24th M6.2 Amatrice and October 30th M6.5 Norcia earthquakes (Akinci et al 2023 and Pitarka et al. 2021).
- We employed a deterministic modeling technique that uses the Graves and Pitarka (GP16) kinematic rupture generator and 1D GFs to produce broadband ground motion time histories up to 10 Hz for these two earthquakes.
- We then provided a comprehensive analysis of the goodness of fit (GoF) between the recorded ground motion data and the results obtained from our simulations.
- We examine the spatial variability of Peak Ground Velocity for the earthquakes using our simulations for the entire study area

THE FK APPROACH

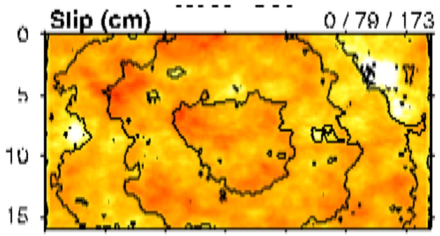
- The frequency-wavenumber (FK) method is one of the most reliable methods for modeling the propagation of seismic waves in a layered half space. It solves the elastic-wave equation in the frequency domain

- Based on 1D velocity model, we use CIA (Hermann et al 2011)
- It is semi-analytical and free from grid constraints.
- This methodology exhibits adaptability to the stratified nature of the regional crust and maintains robust computational stability.
- The solutions obtained through the FK method (Zhu & Rivera 2002) typically align well with propagation frequencies, containing high-frequency ranges required in engineering applications

Physics-Based Ground Motion Simulation Method

Deterministic Approach 0-10 Hz

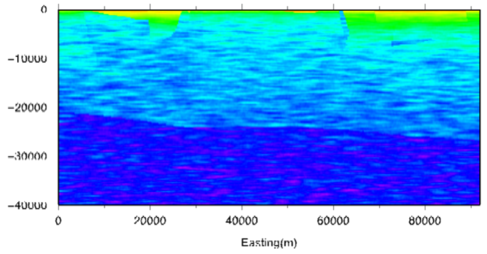
Kinematic Rupture Model



GP Method

Kinematic rupture models generated using a technique developed by Graves and Pitarka, 2016

Wave Propagation
1D Linear anelastic, constant-Q



FK Code

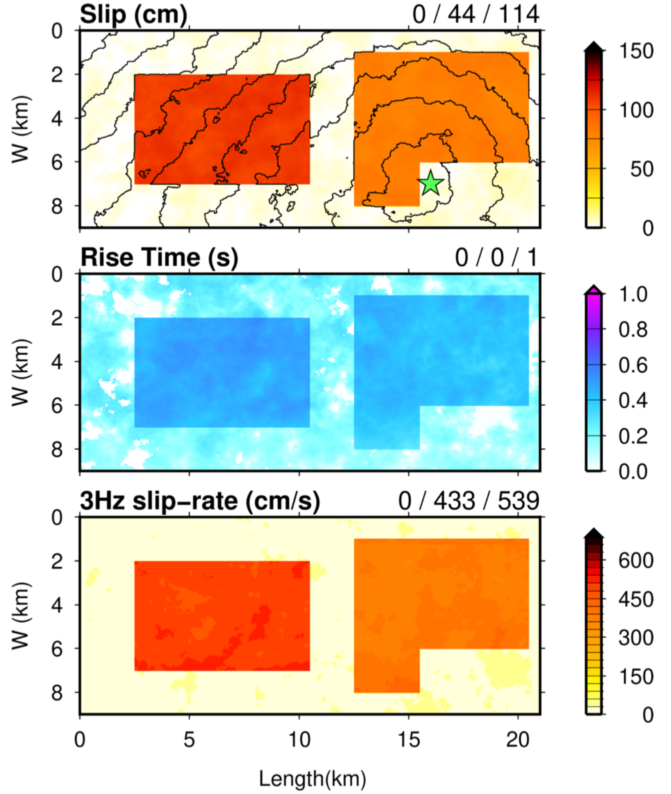
It solves the elastic-wave equation in the frequency domain by setting a cylindrical set of coordinates.

Simulations are performed using a physics based deterministic approach, modeling the earthquake rupture and elastic wave propagation and running the parallelized CPU version of the FK code on the

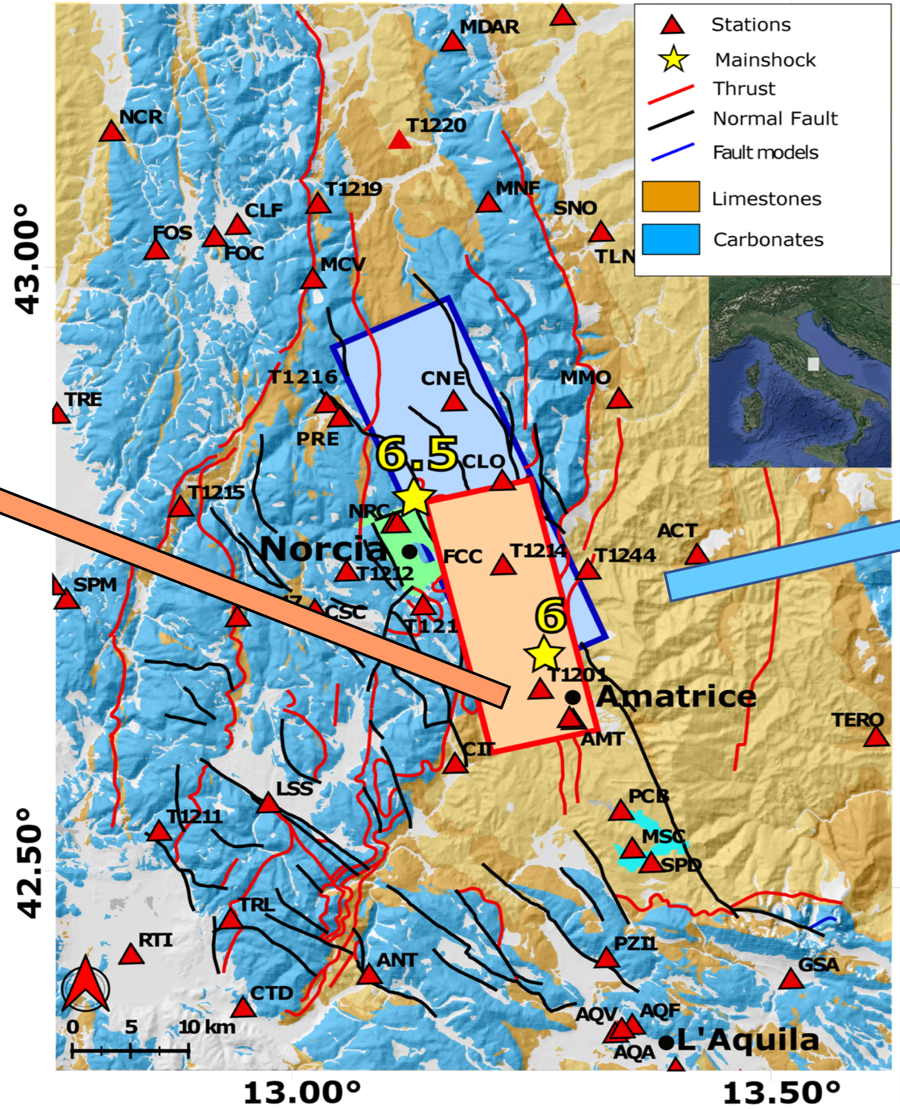
Supercomputer Mercalli INGV Cluster
Model Domain covers : 102kmx88kmx31km
Min grid spacing: 25 m
Min time spacing dt: 0.012 s
Min Vs: 400m/s
F_{max}: 10Hz
Ground motion duration: 50 s
CPUs: 1 (serial runs)
Wall time : max 10 min per station

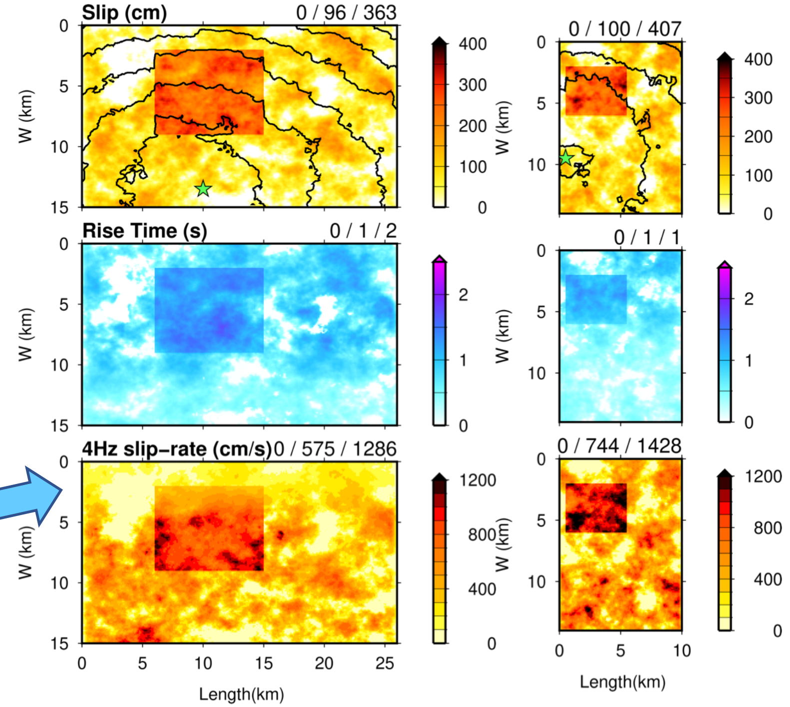
Comparison with sw4 3D simulations on CINECA Cluster
Wall time ~10 hours
CPUs: 2048

KINEMATIC RUPTURE MODELS FOR NORCIA AND AMATRICE EARTHQUAKES



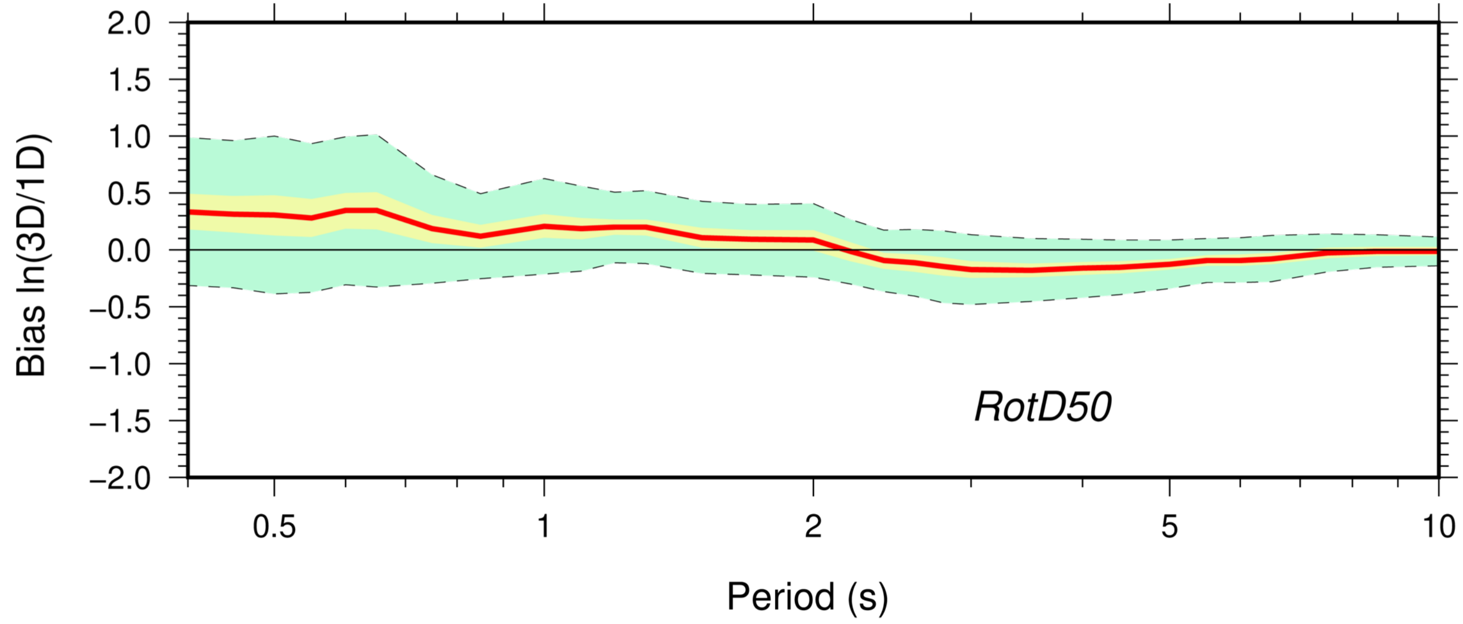
The kinematic rupture models for the M_w 6.2 Amatrice earthquake adopted from Tinti et al (2016) was realized using the hybrid technique of Pitarka et al. (2016) that integrates deterministic two large slip patches with the rectangular formation with random perturbations





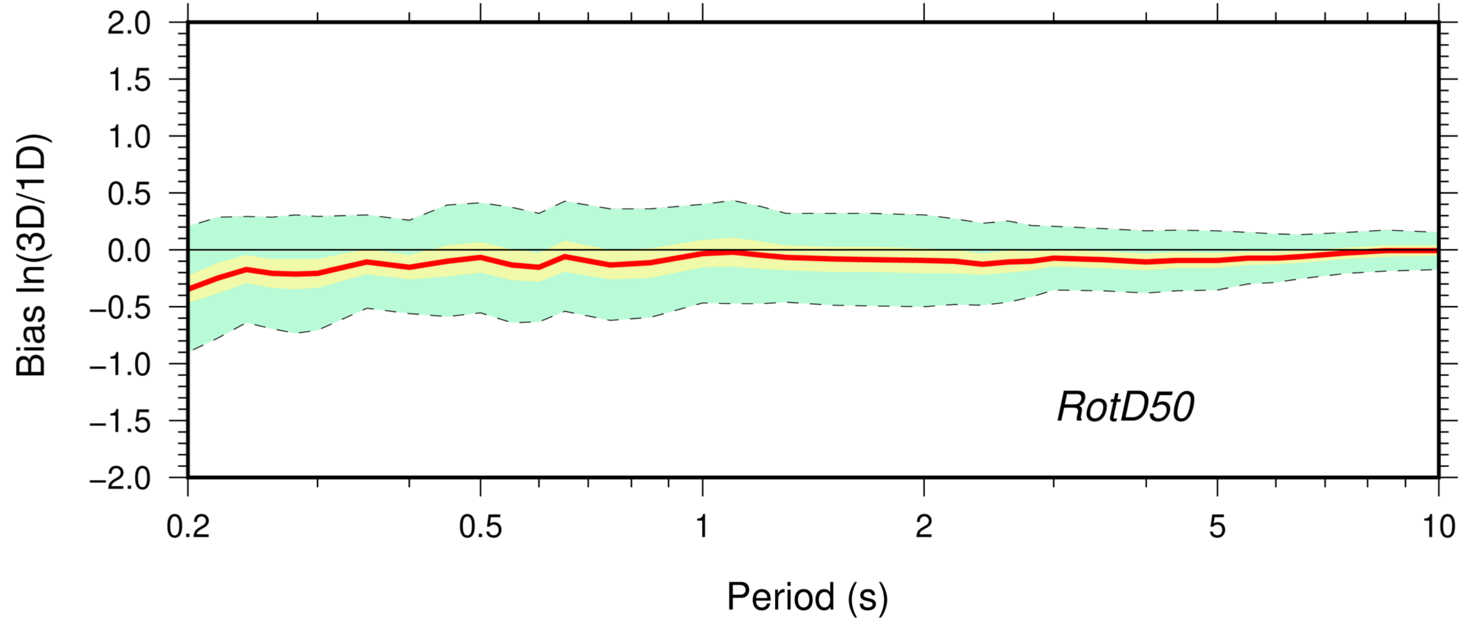
The Kinematic rupture model for the M_w 6.5 Norcia earthquake adopted from Scognamiglio et al. (2018) using a hybrid approach (Pitarka et al., 2016) that combines deterministic large slip patches with rectangular shape, with random perturbations.

3D/1D COMPARISON



Amatrice, M_w 6.2

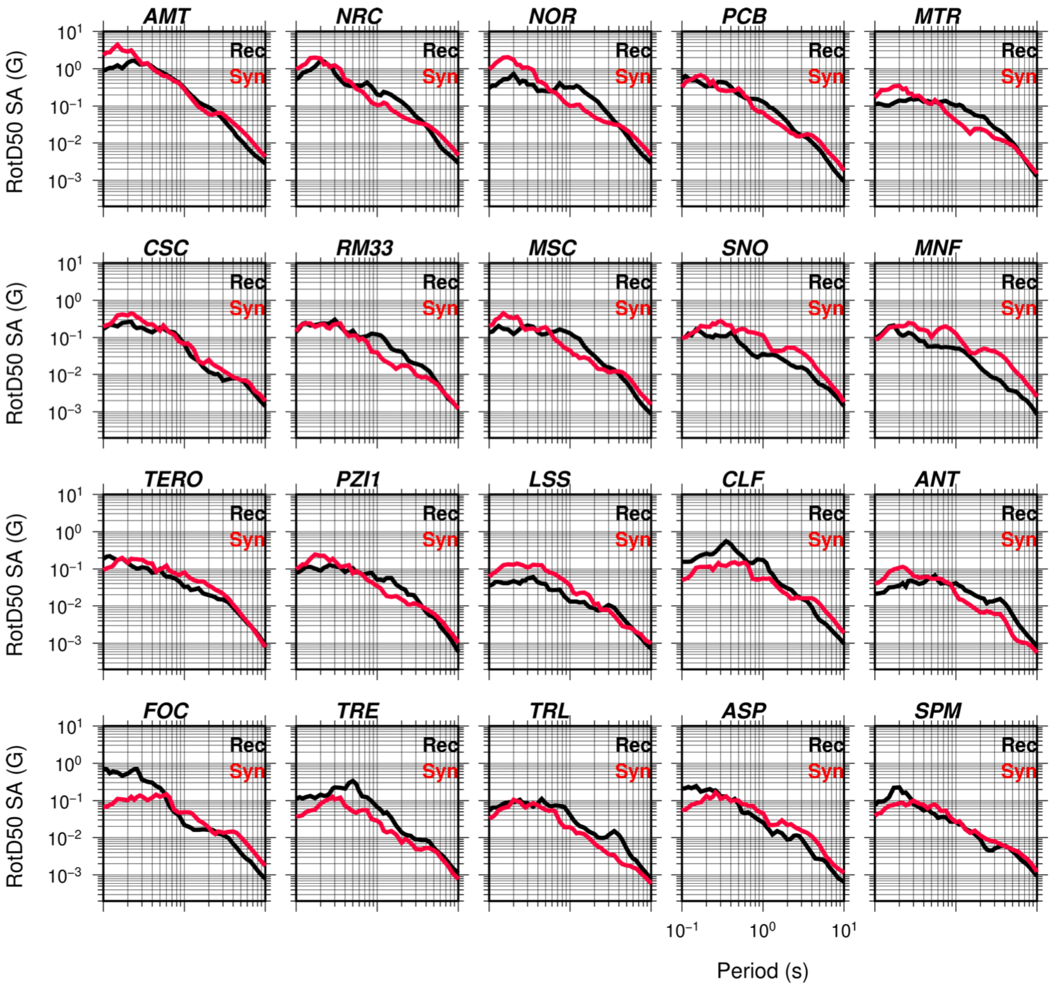
Amatrice (top) and Norcia (bottom) earthquakes GoF plot showing the model bias (solid line) and standard deviation (dashed lines) of residuals between the 3D and FK simulated RotD50 SA values in the 0.4–10 s period range (Amatrice) and 0.2-10 s period range (Norcia), averaged over 36 (Amatrice) and 37 (Norcia) stations.



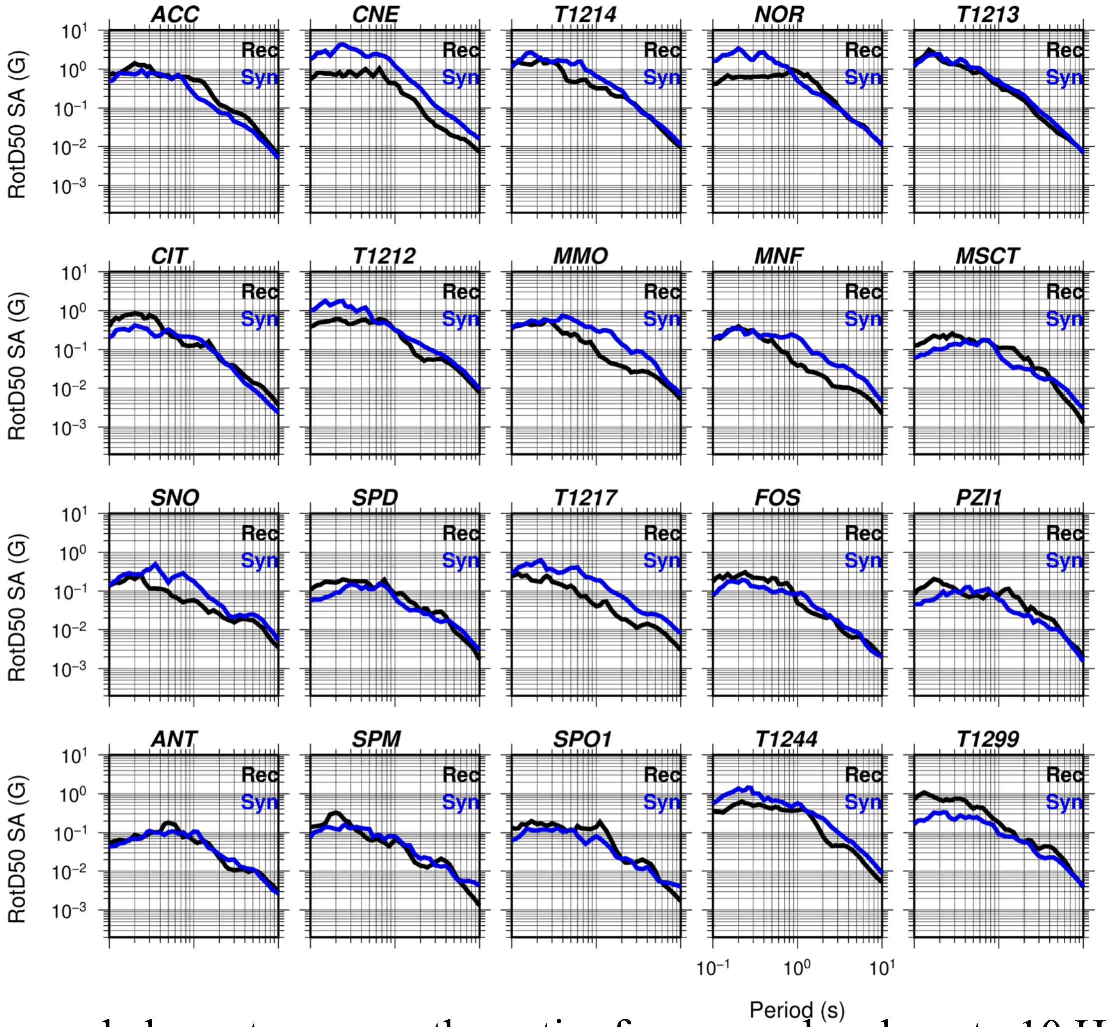
Norcia, M_w 6.5

RECORDED AND 1D-FK SIMULATED SPECTRAL ACCELERATION

Amatrice M_w 6.2



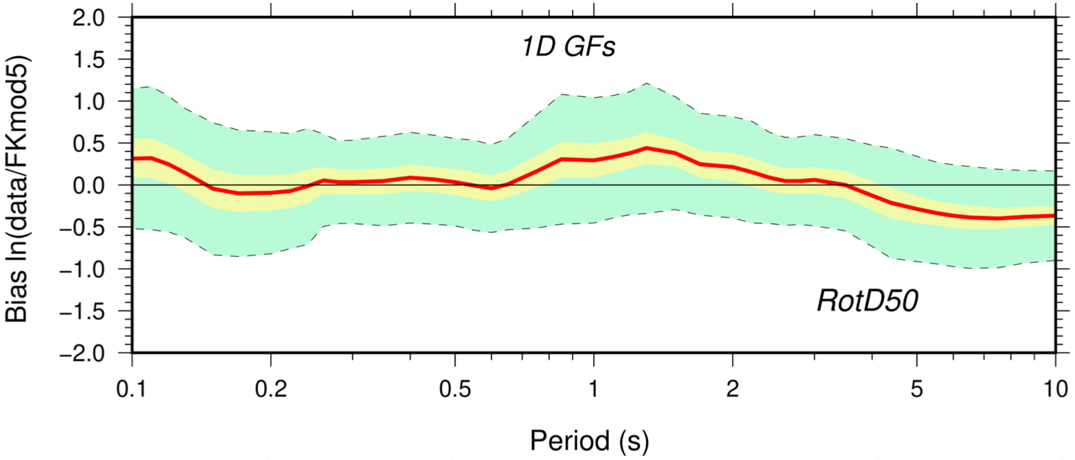
Norcia M_w 6.5



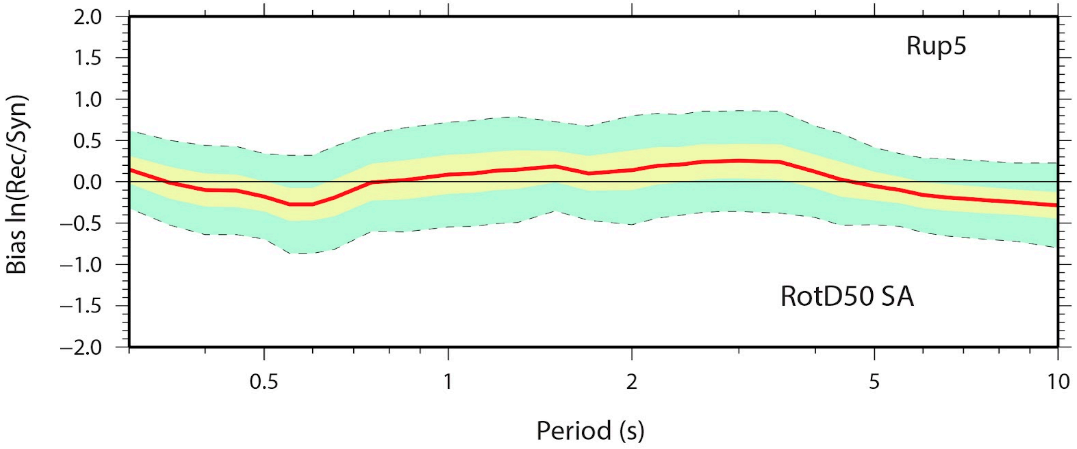
- The general shape of the simulated spectra closely matches that of the recorded spectra across the entire frequency band, up to 10 Hz.
- The most significant differences between the synthetic and actual data occur at periods shorter than 1 second.

Simulated 1D- FK Ground Motion Validation:

Comparison with recorded time histories (0-10Hz) for Amatrice M_w6.2

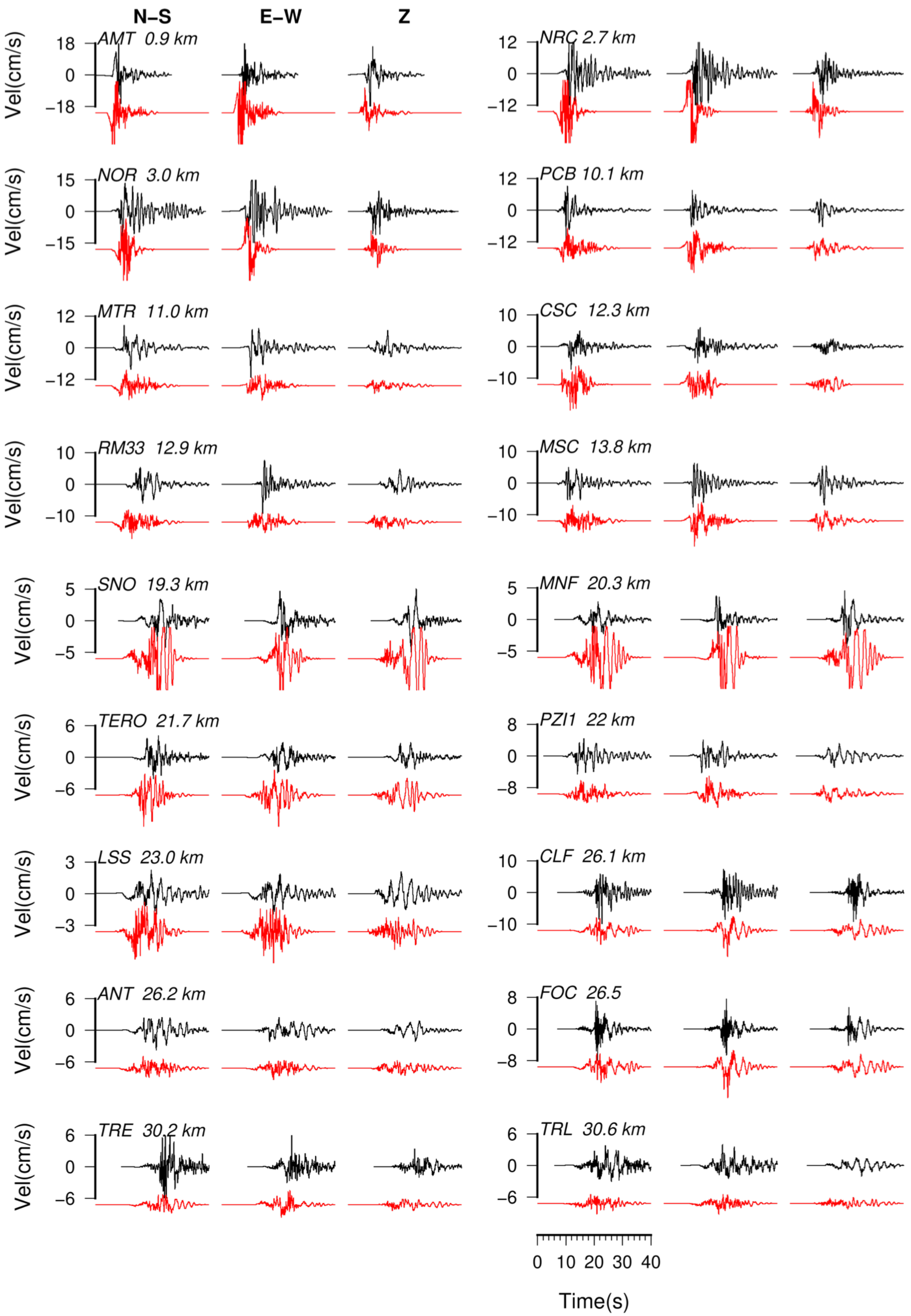


FK -1D



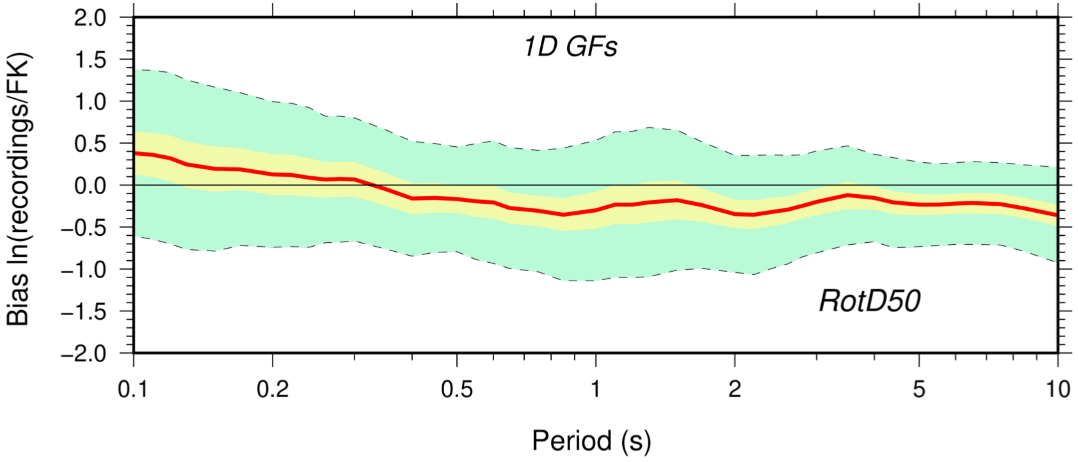
SW4 -3D

(Akinci et al 2023, submitted)

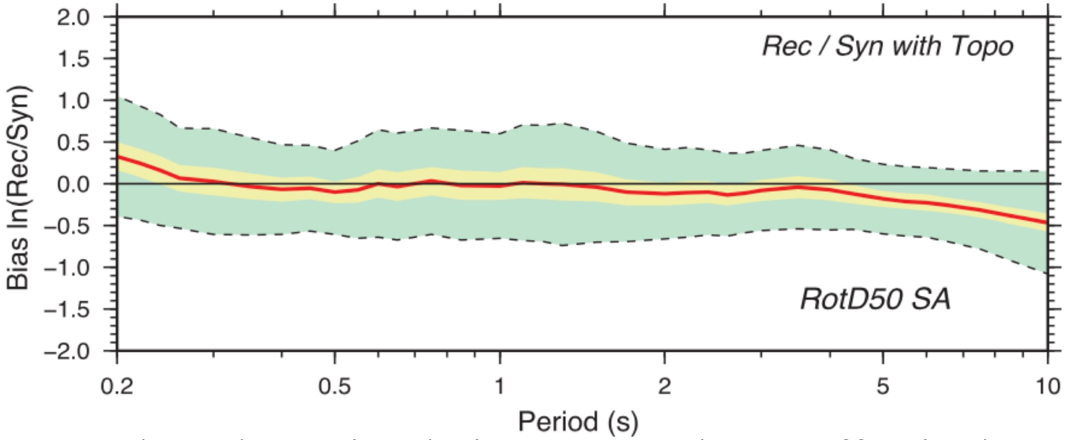


- FK-based 1D simulation approach can effectively reproduce the recorded ground motion in the frequency **range of 0-10 Hz**.
- Comparisons between the 1D method and the 3D indicate minor differences between the two approaches (Range 0-3 Hz)

Simulated Ground Motion Validation: Comparison with recorded time histories (0-10Hz) for Norcia Mw6.5

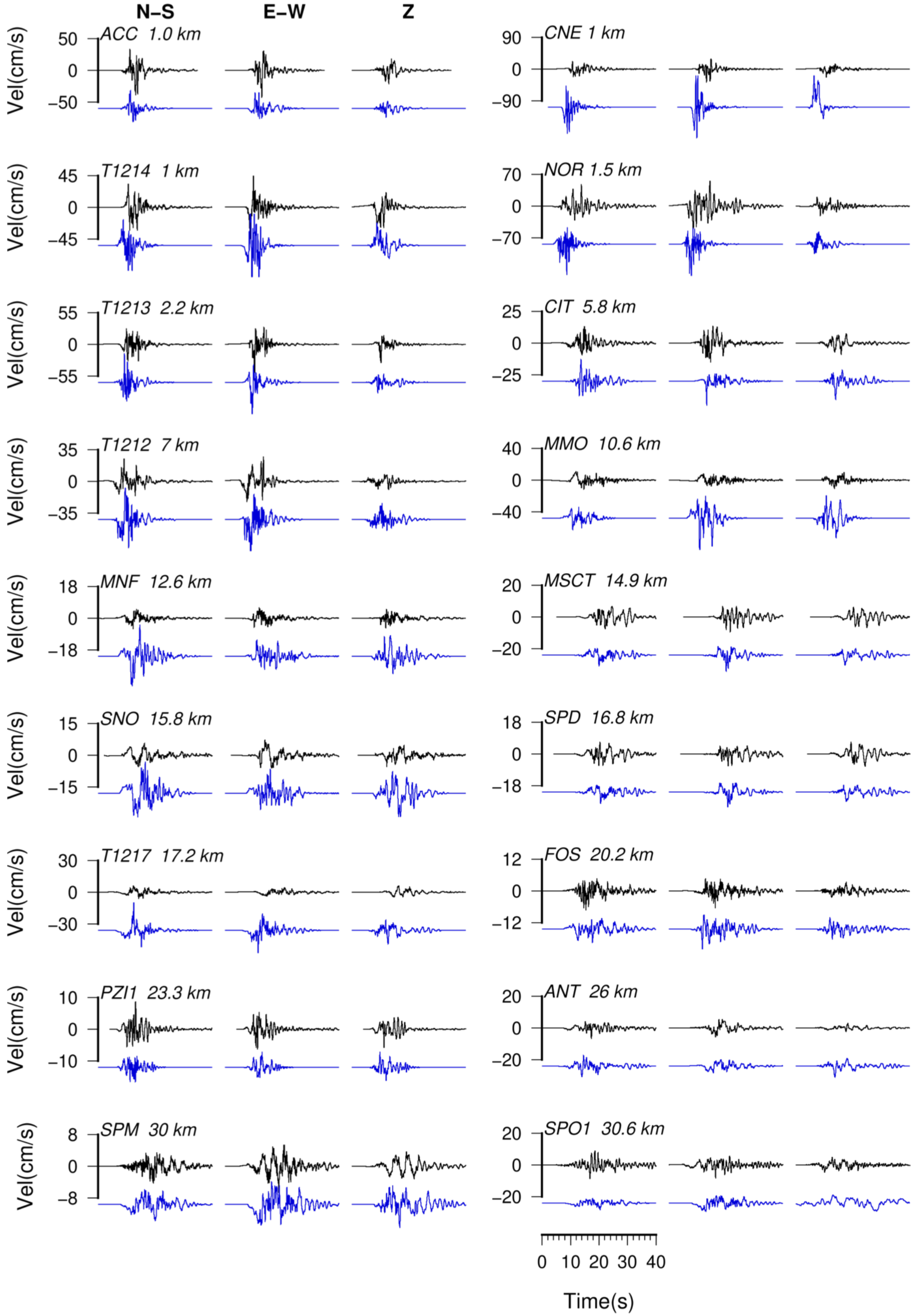


FK -1D



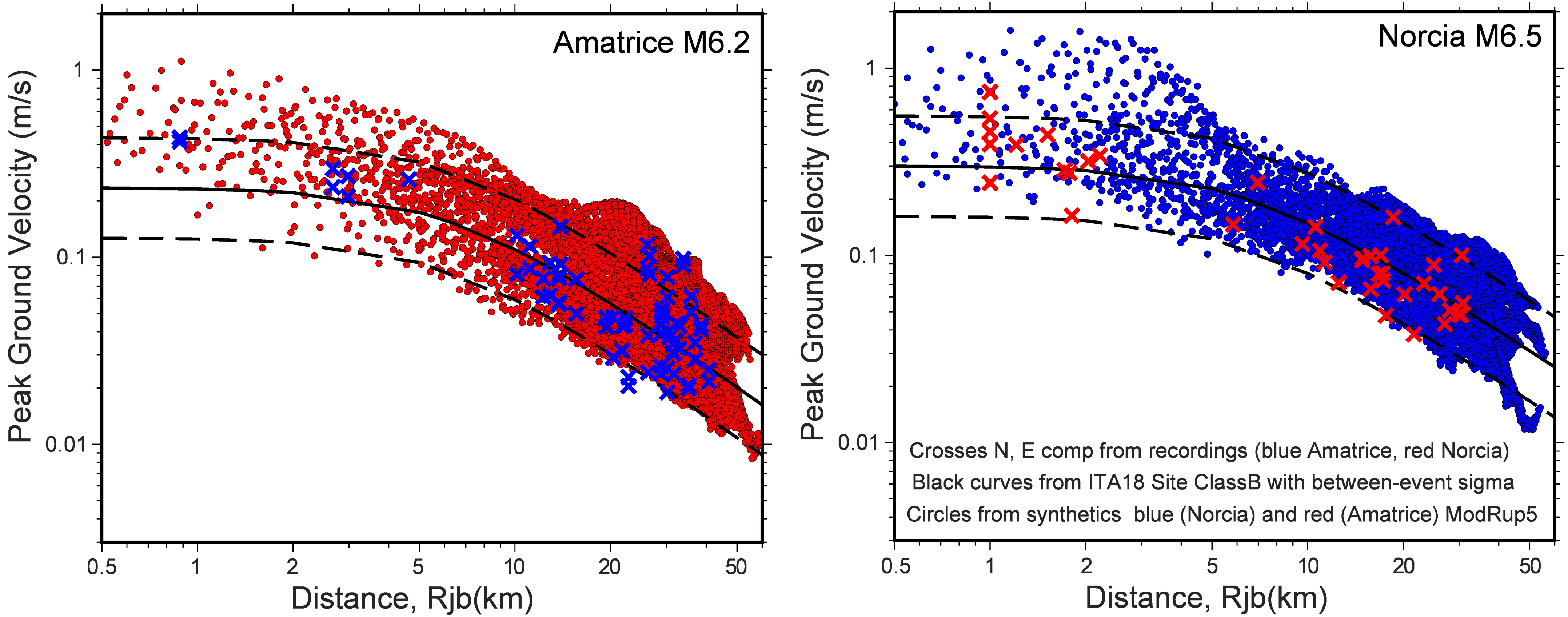
SW4 -3D

(Pitarka et al 2021)



- FK-based 1D simulation approach can effectively reproduce the recorded ground motion in the frequency **range of 0-10 Hz**.
- Comparisons between the 1D method and the 3D indicate minor differences between the two approaches (Range 0-5 Hz)

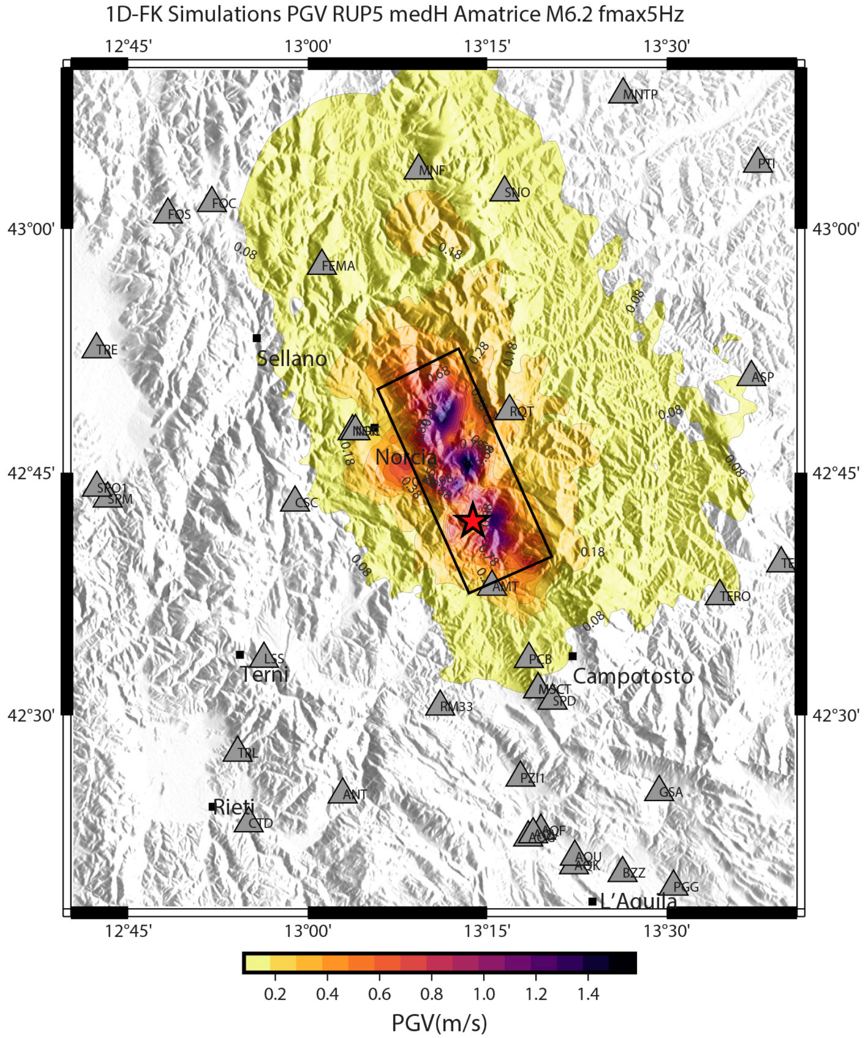
Comparing simulations with GMMs and recordings



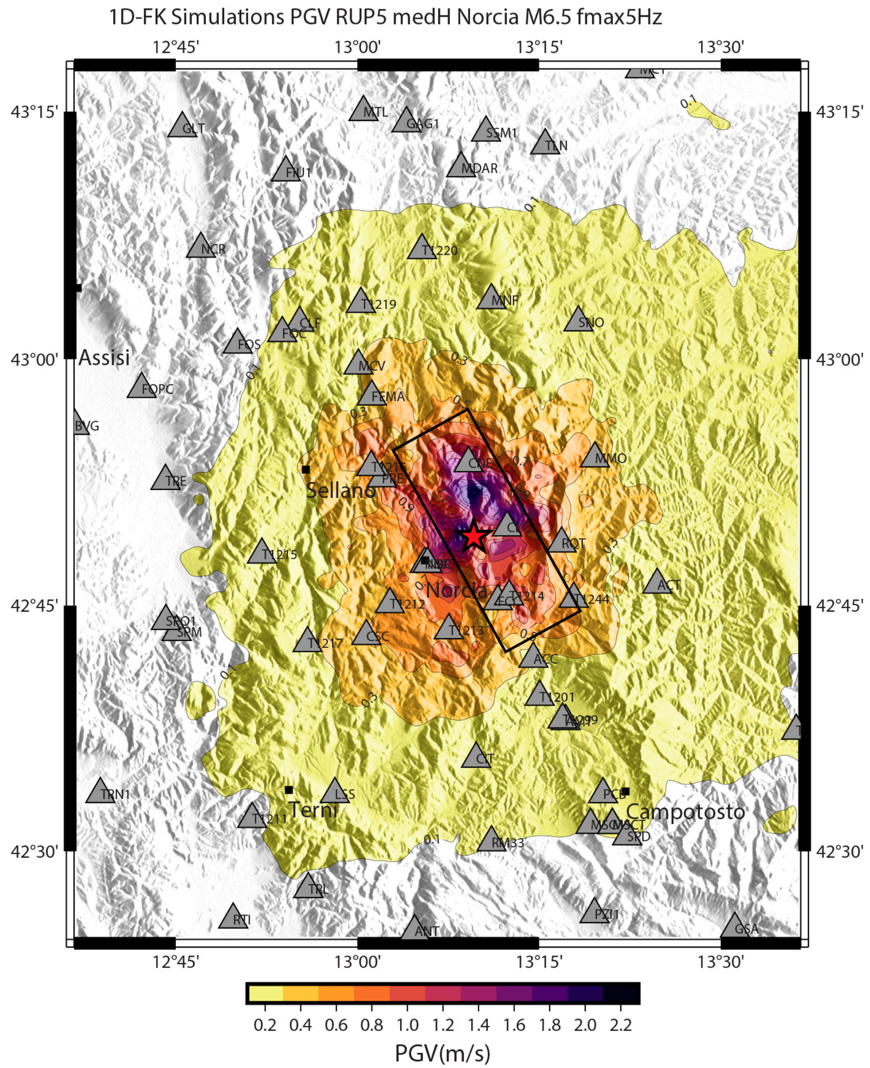
- We compared the PGV for synthetics with recorded low passed at 5Hz.
- The fit is good in the case of PGV for both Amatrice and Norcia.
- Large dissipation at near-source of simulated PGV depends on the slip distribution and strength, and corresponds to more than one standard deviation of the considered GMMs ITA18.

Maps of Simulated PGV: Sensitivity of Ground Motion Amplification Pattern to Slip Distribution

Amatrice M_w 6.2



Norcia M_w 6.5



- The most significant ground motions observed at sites above the fault could express the effects of large slip patches.

- It is clear that in the case of Amatrice we have a directivity effect more evident than the case of Norcia

CONCLUSIONS

- We conducted deterministic simulations of M_w6.2 Amatrice and M_w6.5 Norcia events, using a broad band (0-10Hz) simulation method and GFs computed with the CIA 1D velocity model.
- We demonstrate the reliability of 1D deterministic ground motion simulations in reproducing observed ground motion in the frequency range 0-10 Hz and the source-related spatial variability for the two earthquakes
- The comparisons between the synthetic ground motion computed with the 1D method and the 3D finite-difference method performed in previous studies (Pitarka et al., 2021, Akinci et al., 2023) indicate minor differences between the two approaches in the frequency range 0-3 (0-5) Hz.
- Our method enables us to obtain accurate simulations at higher frequencies comparable to those obtained from the 3D method. Achieving similar results with the 3D method would require significantly increased computational resources.
- Our findings suggest that 3D computationally expensive methods are not always necessary for this task.
- This approach holds promise for seismic hazard assessment in Central Italy, enabling significant savings compared to 3D modeling.

WORK IN PROGRESS

- This work has been presented at last AGU and received a considerable attention: *P. Artale Harris, A. Pitarka & A. Akinci, Broadband Ground Motion Simulations of M≥6.0 Earthquakes in Central Italy using a Frequency-Wavenumber Approach* S51H-0293
- It will be presented at the next WCEE2024 conference and a proceeding was submitted: *P. Artale Harris, A. Pitarka & A. Akinci, Comparing* ***1D/3D Ground Motion Simulations*** *for Earthquakes in Central Italy*
- It will be presented at next EGU24 where an analysis of model sensitivity will be done: *P. Artale Harris, A. Pitarka & A. Akinci Broadband Ground Motions Simulations for M≥6.0 Earthquakes in the 2016/2017 Central Italy Seismic Sequence through a 1D Frequency-Wavenumber Approach: a* ***Velocity Models Sensitivity Analysis***
- We are preparing a paper with the presented work and some extensions as well
- We are working on simulations based on **Frequency-dependent of the attenuation**

THANK YOU FOR YOUR ATTENTION!