Physics-based earthquake ground-motion simulations in South Iceland

Victor Hernández

Rajesh Rupakhety

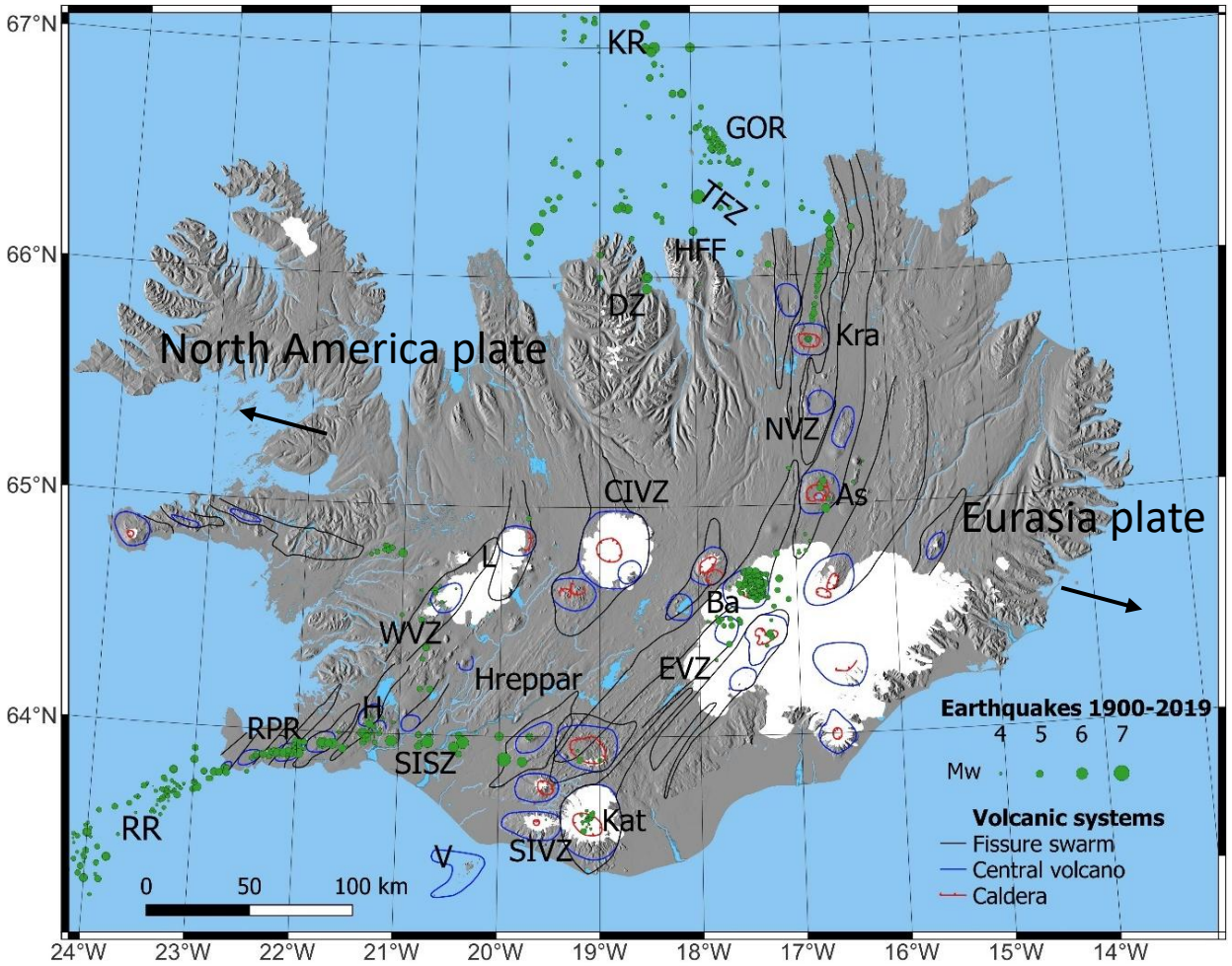
Umhverfis- og byggingarverkfræðideild

Háskóla Íslands

Outline

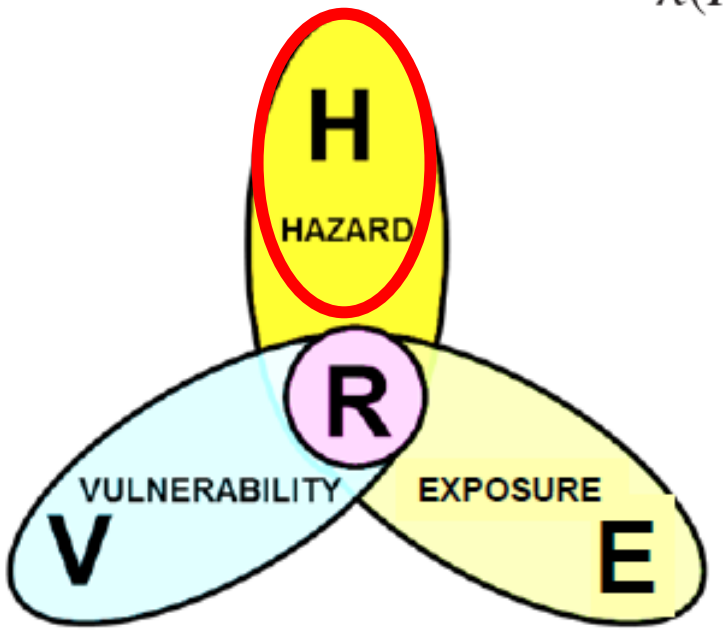
- Motivation and context
- Physics-based simulations (PBS)
- PBS of the 2000 South Iceland earthquakes
- Engineering applications
- Conclusions & future perspectives

Seismotectonic context



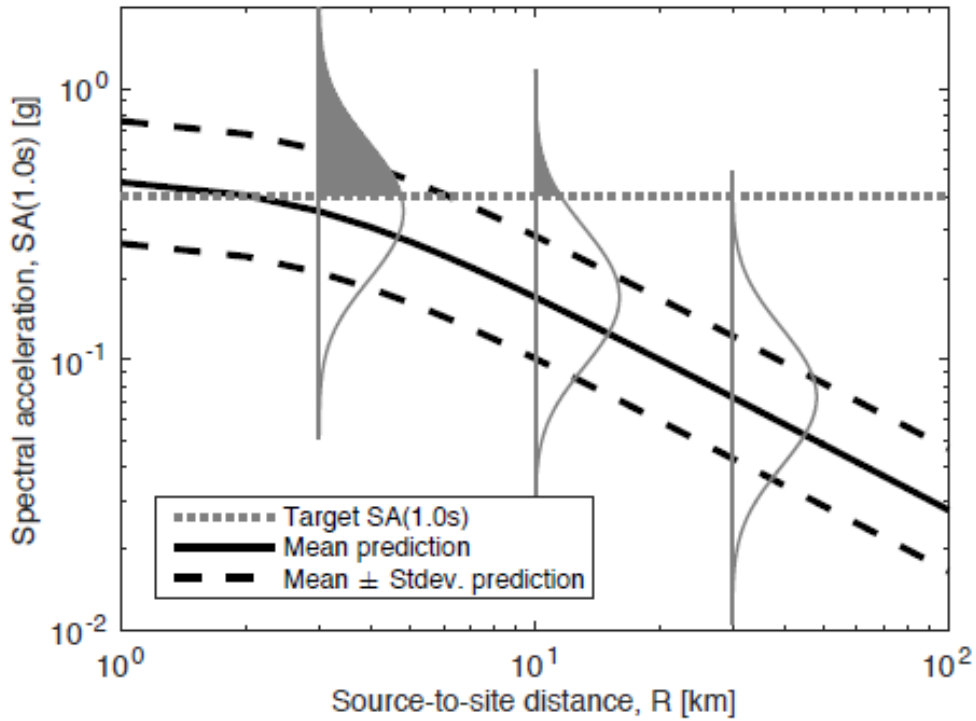
Earthquake epicenters 1900–2019 (Jónasson et al., 2021) and volcanic systems of Iceland (Einarsson & Sæmundsson, 1987).

Seismic risk and hazard

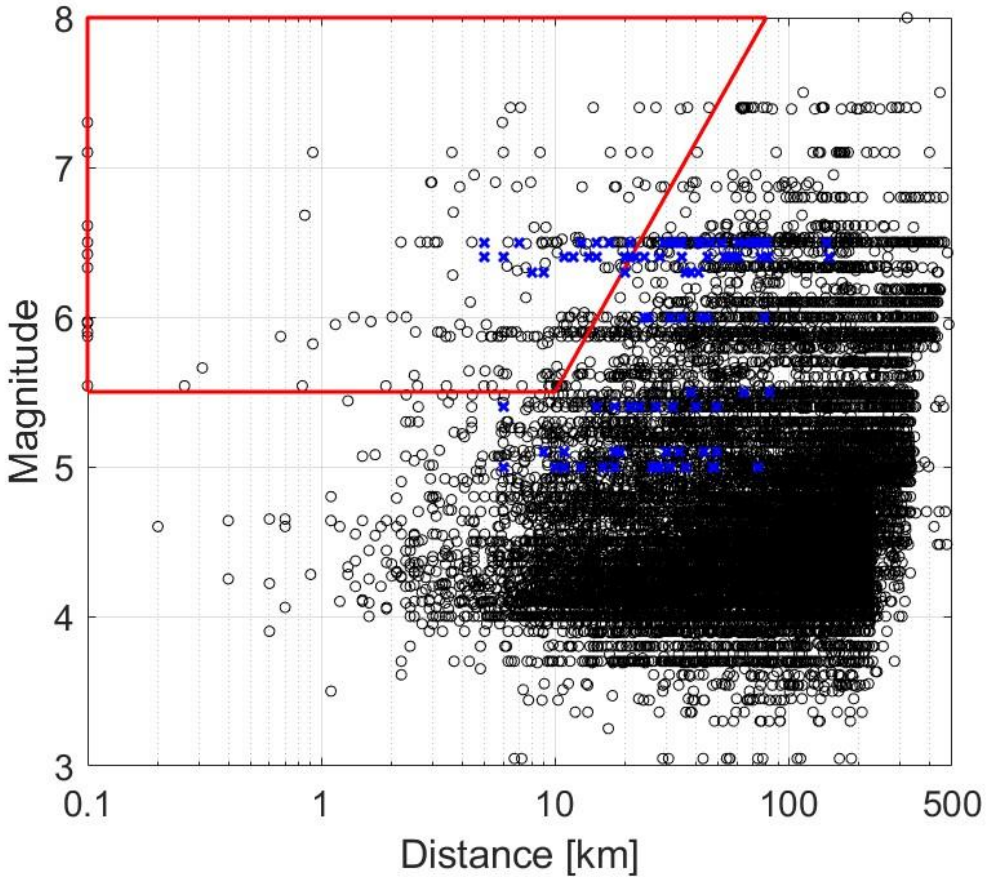


Ground-motion estimation

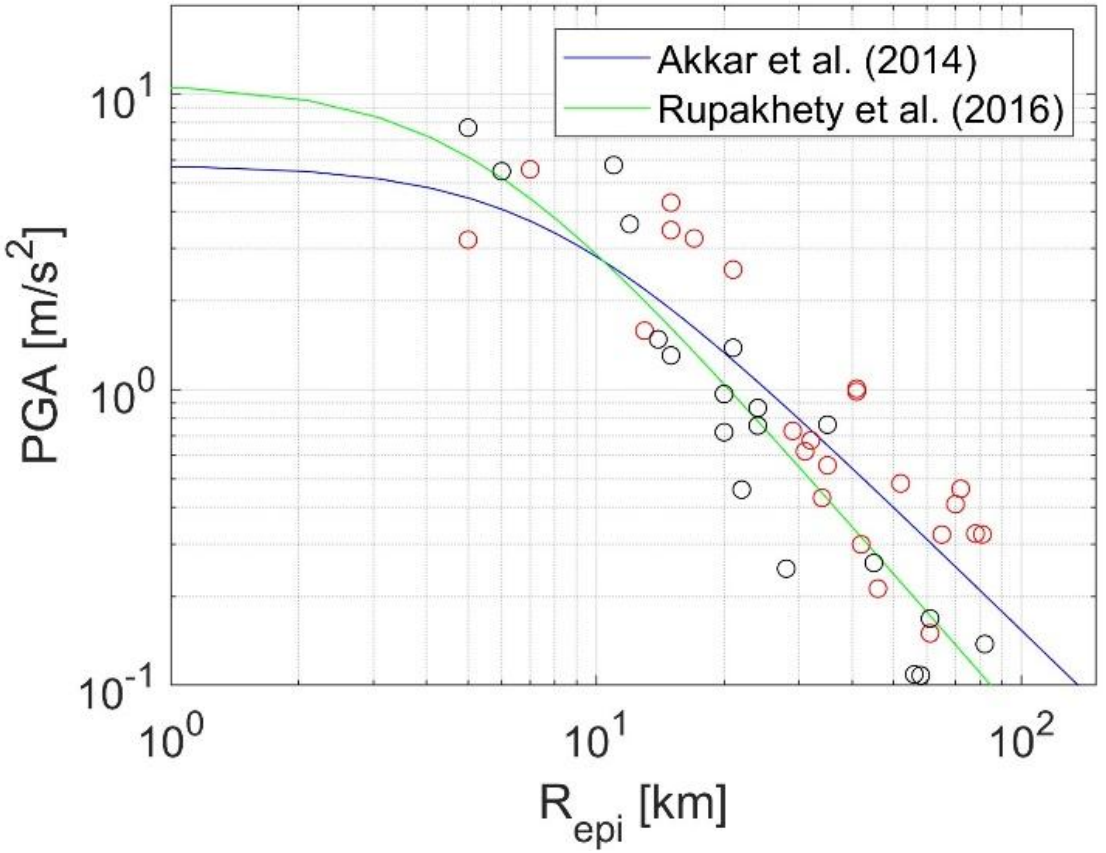
$$\lambda(IM > im) = \sum_{j=1}^{n_{sources}} \sum_{i=1}^{n_{rup_j}} P\left(IM > im | rup_{i,j}, site\right) \lambda\left(rup_{i,j}\right)$$



Knowledge gaps in ground-motion observations and empirical modelling

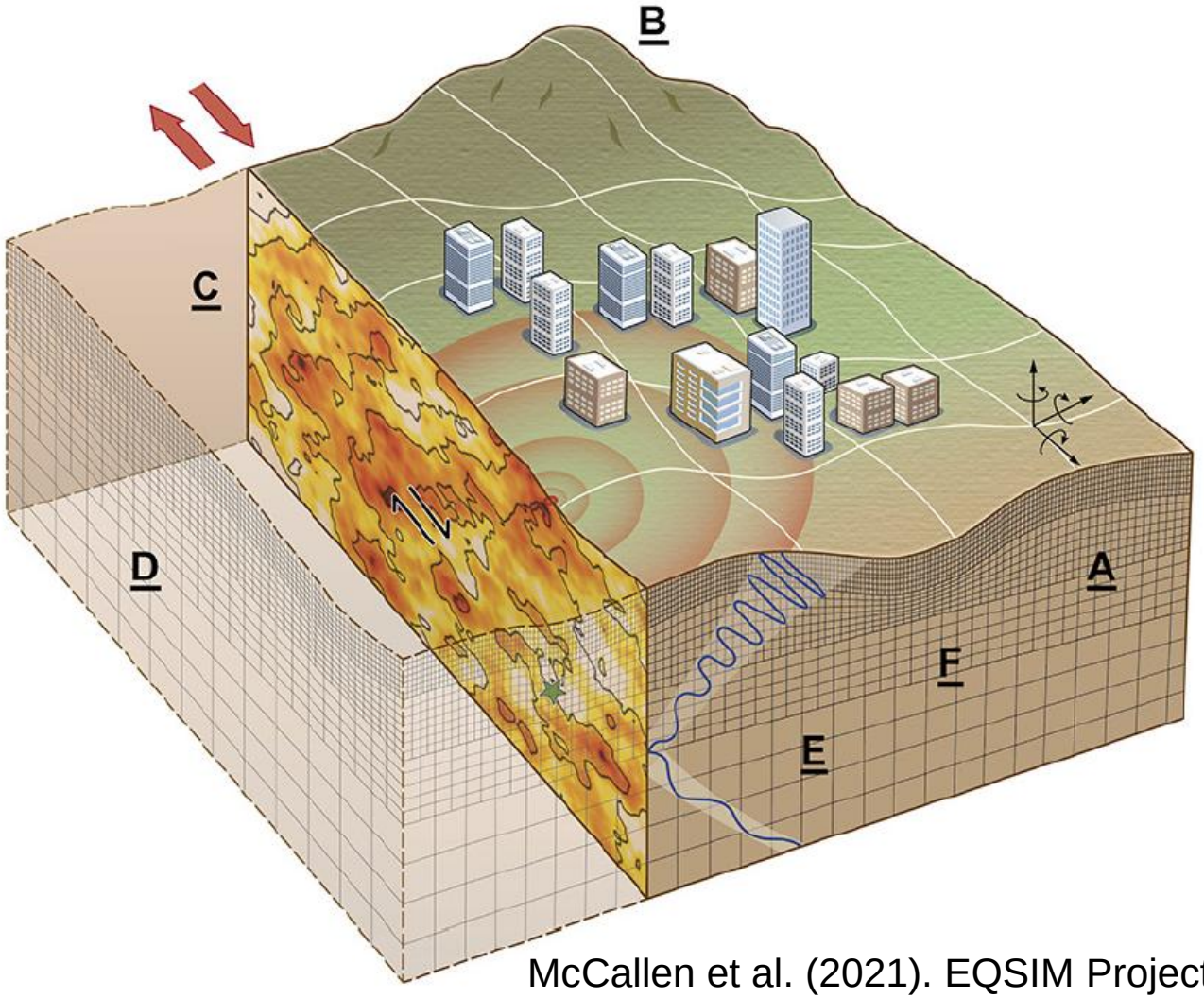


Magnitude-distance distribution of the ESM (Lanzano et al. 2019) and the IceSMN databases.



PGAs from the 2000 South Iceland events compared with the predictions from two GMMs.

Physics-based simulations (PBS)



McCallen et al. (2021). EQSIM Project

"Source-to-site(-to-structure)" numerical simulation of seismic wave propagation, including:

- seismic source;
- near-fault effects;
- source-to-site propagation path in heterogeneous Earth media;
- local site effects due to 3D geological and topographical features;
- up to buildings in urbanized environments (soil-structure-interaction).

Workflow to generate regional-scale PBS

Input data

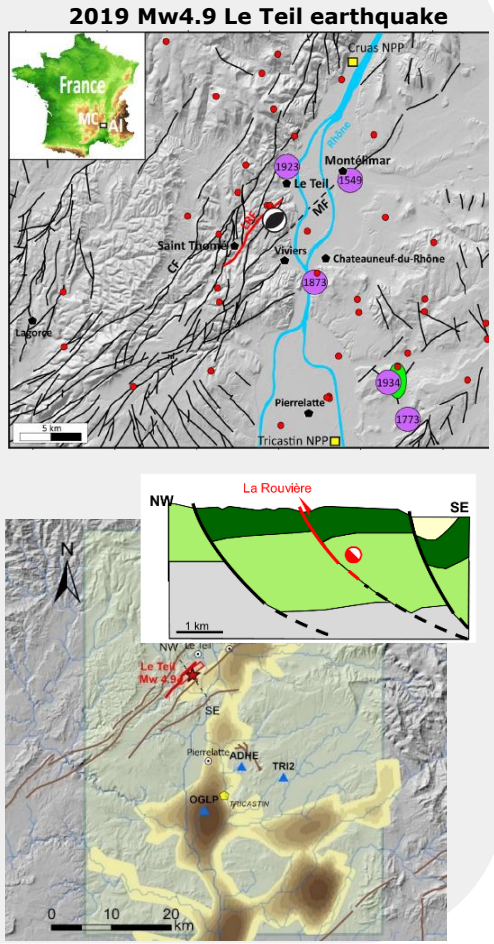
SEISMOTECTONIC CONTEXT (FAULTS)

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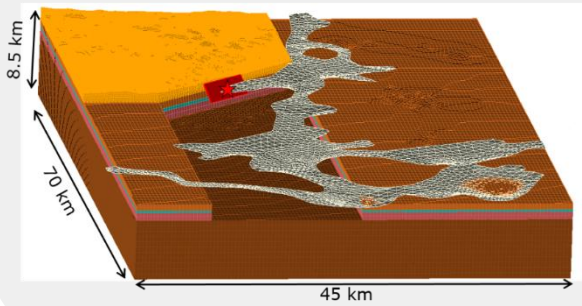
TOPOGRAPHY /BATHYMETRY

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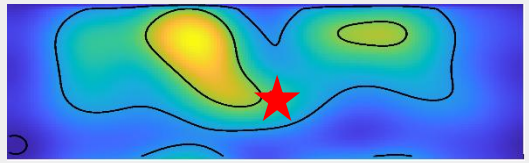
GEOLOGICAL-GEOTECHNICAL-GEOPHYSICAL MODEL



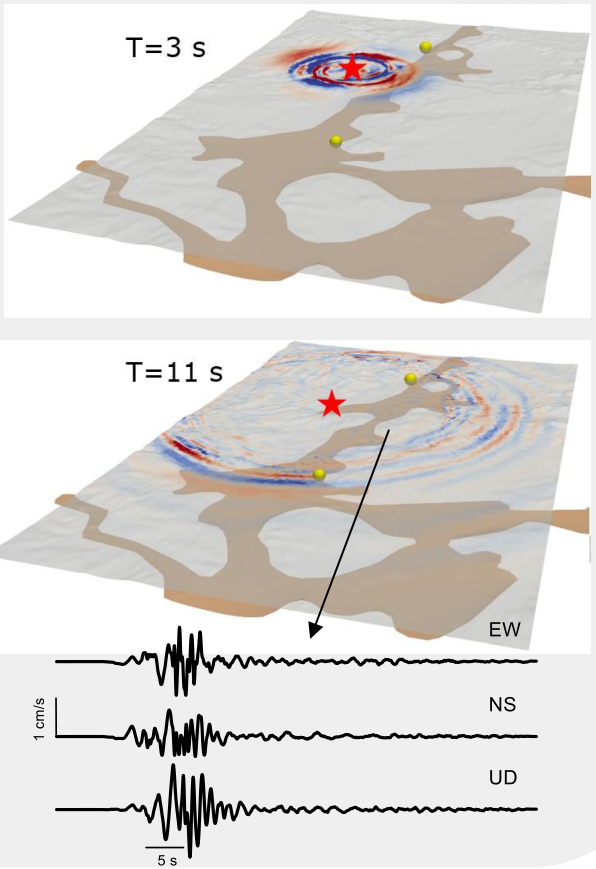
Set-up of the 3D numerical model



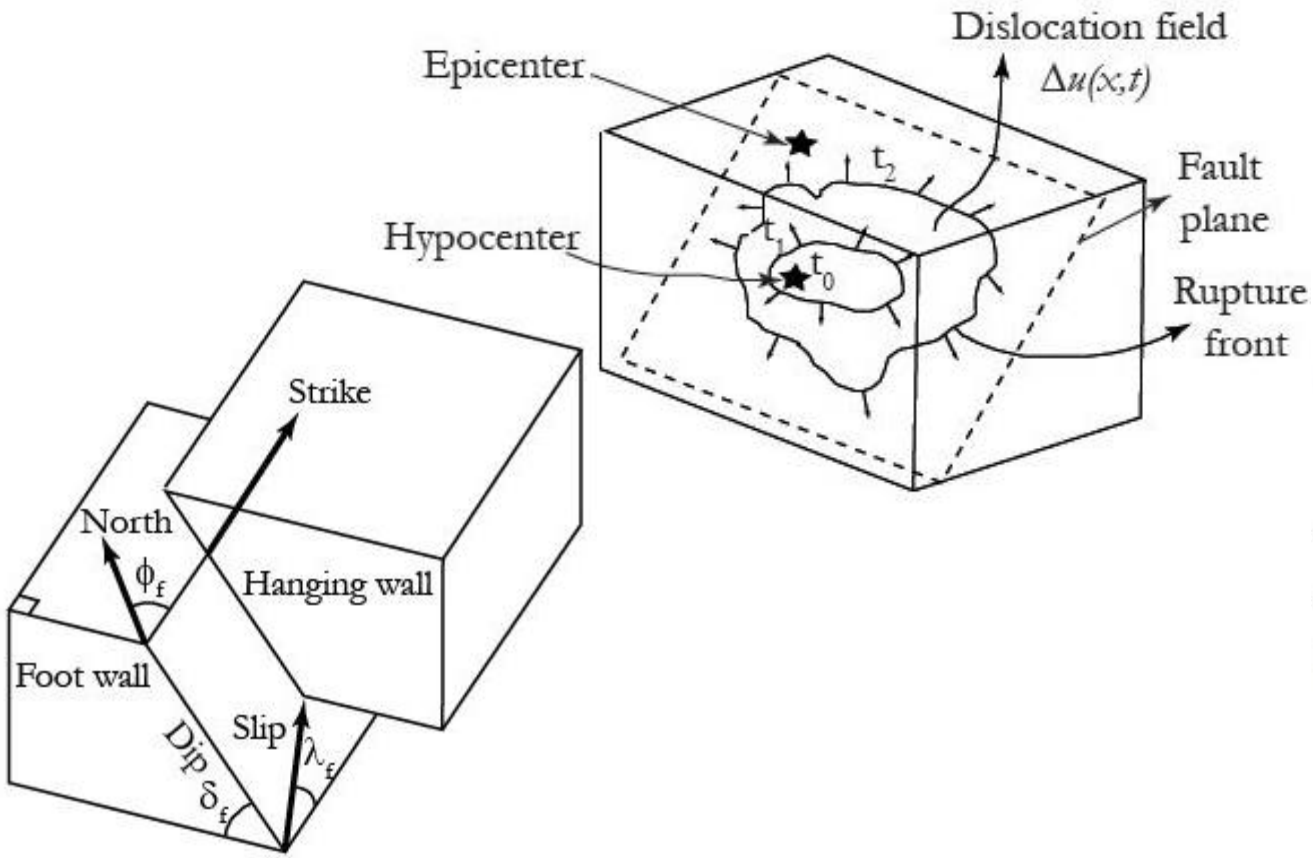
Fault rupture Model

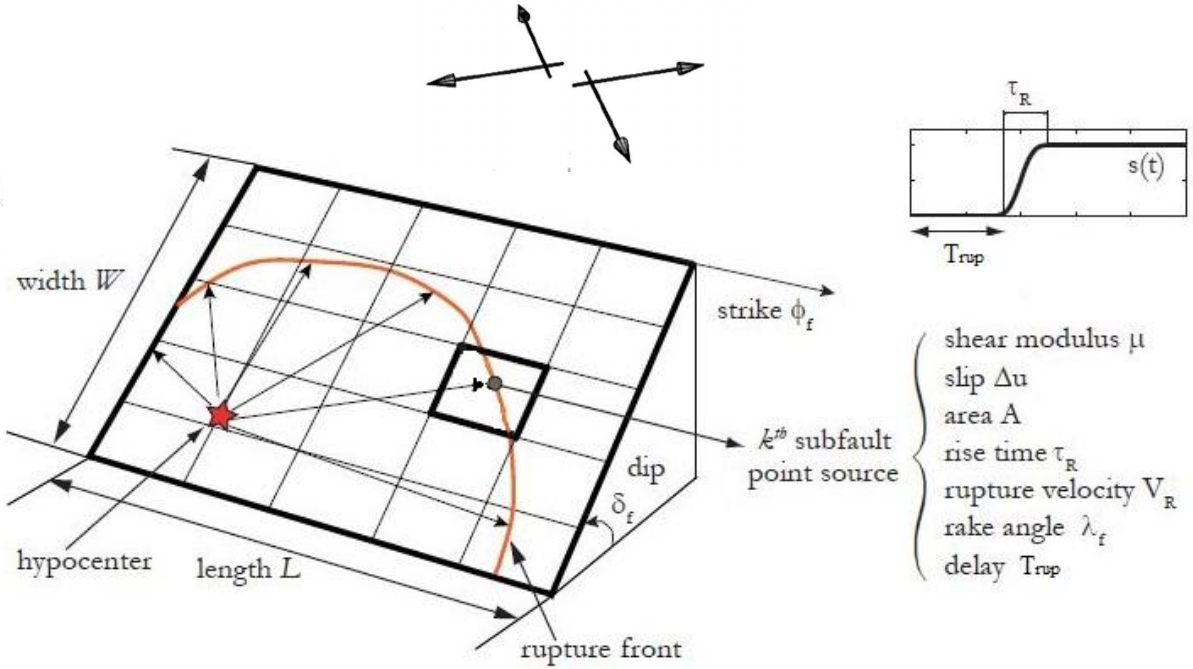


PBS - HPC



Seismic source modelling

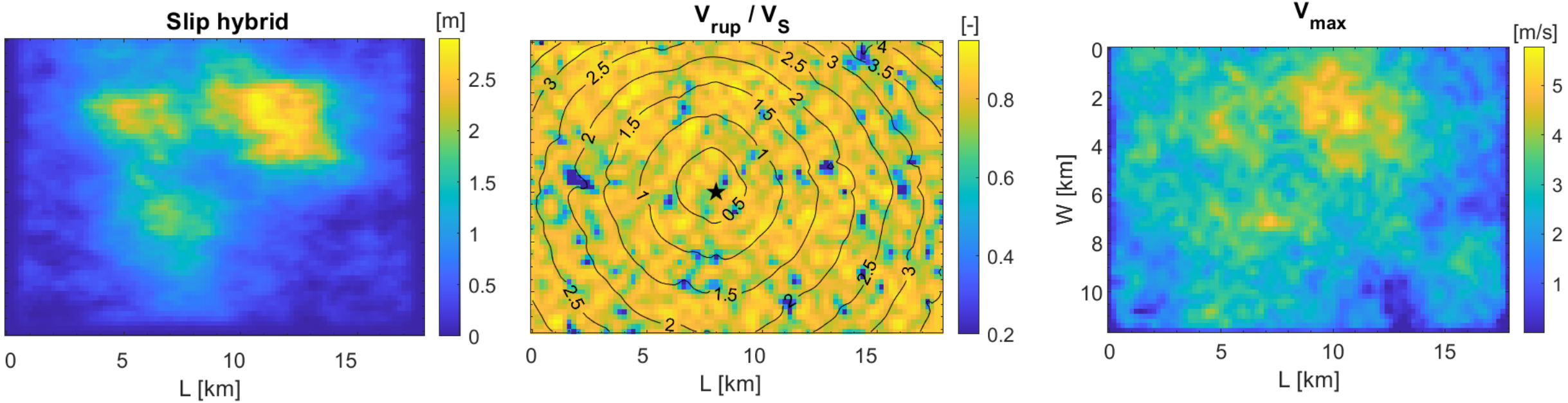




Pseudo-dynamic rupture generator
Rupture parameters for 21 June 2000 earthquake

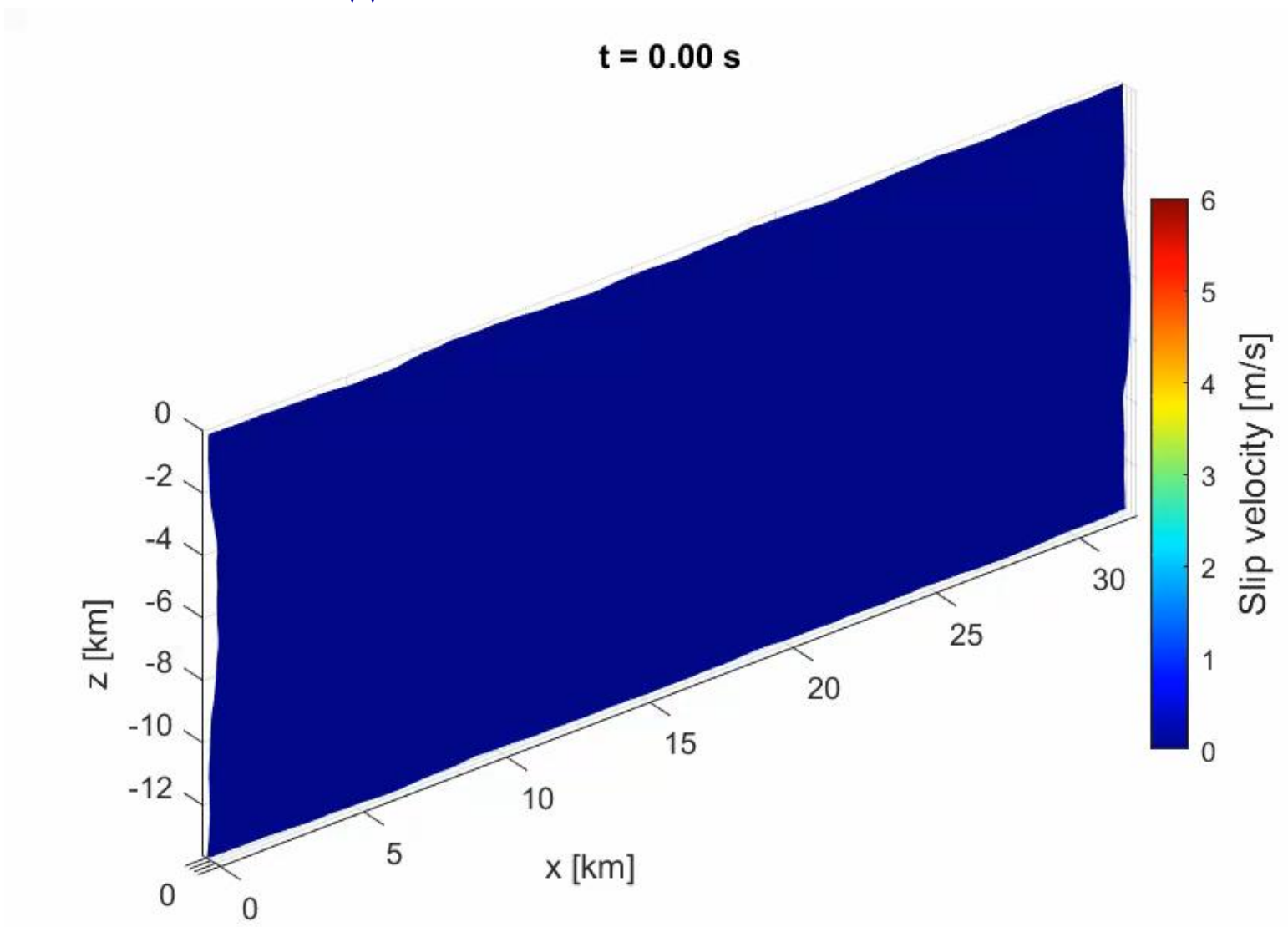
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Multivariate spatially correlated random fields



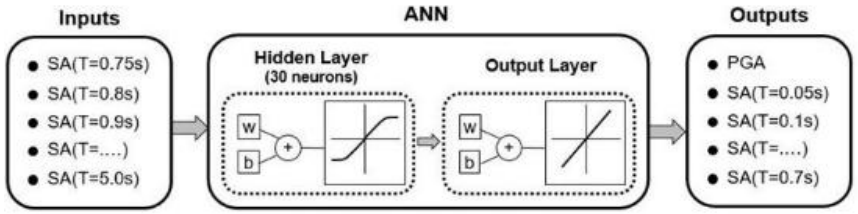
Hernández-Aguirre, V. M., Rupakhety, R., Paolucci, R., Smerzini, C., Vanini, M., Bessason, B., & Erlingsson, S. (2026a). A Kinematic Rupture Generator for Ground-Motion Simulations: Validation and Scenarios in South Iceland. *BSSA, 116*(5), 1947-1964. https://doi.org/10.1785/0120260134

Rupture for a M_W7 scenario in South Iceland

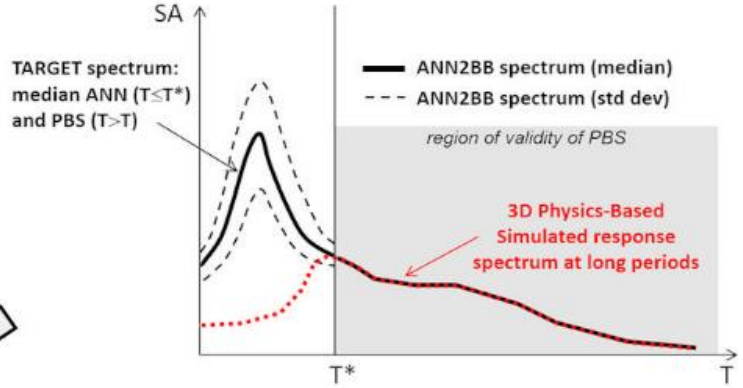


ANN2BB: Broadband ground motions using Artificial Neural Networks

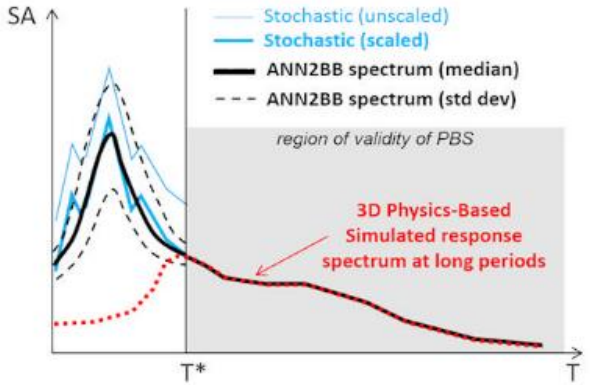
(1) Training of an Artificial Neural Network (ANN) based on a dataset of strong-motion recordings



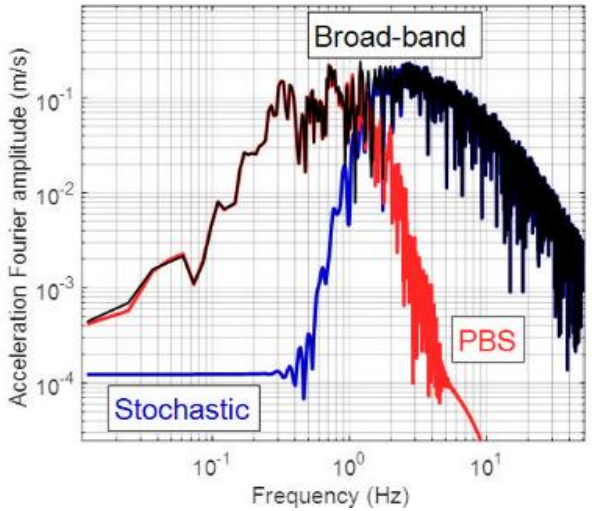
(2) Application of ANN to predict short period spectral ordinates based on PBS results (T≥T*)



(3) Simulation and linear scaling of a stochastic signal to approach the target ANN2BB spectrum

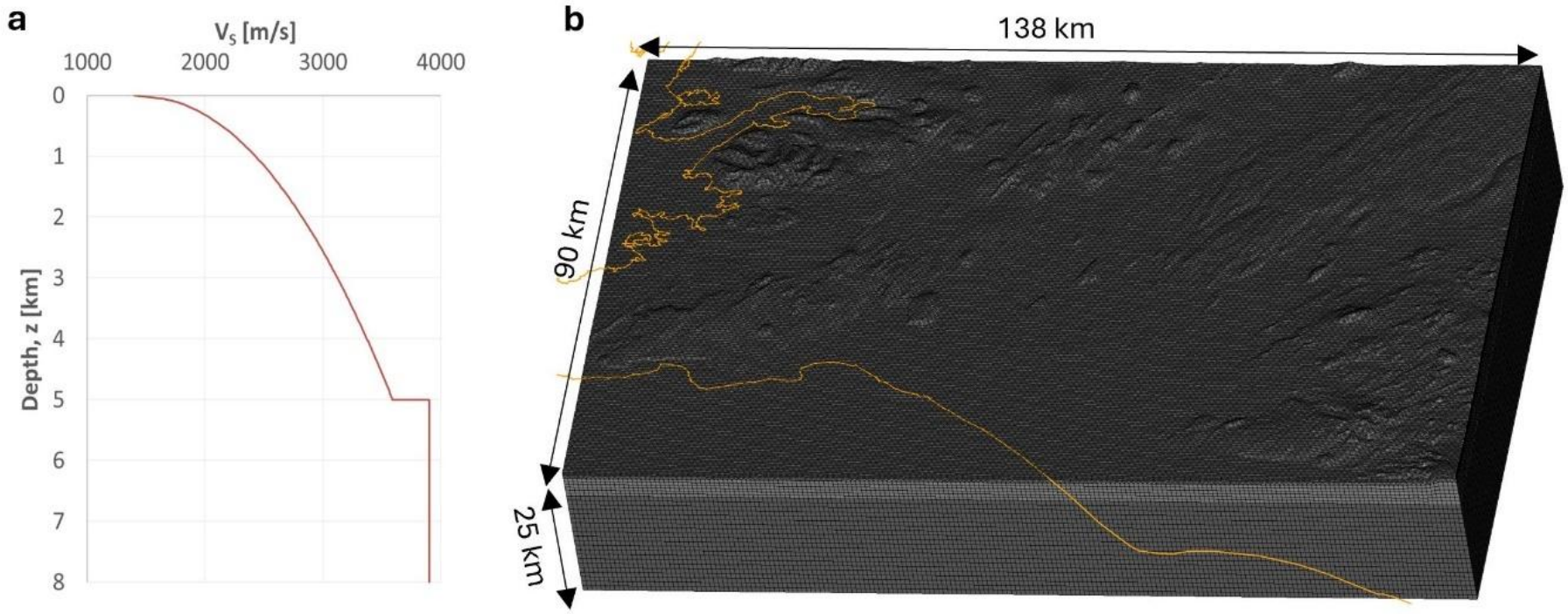


(4) Combination of stochastic and PBS signals



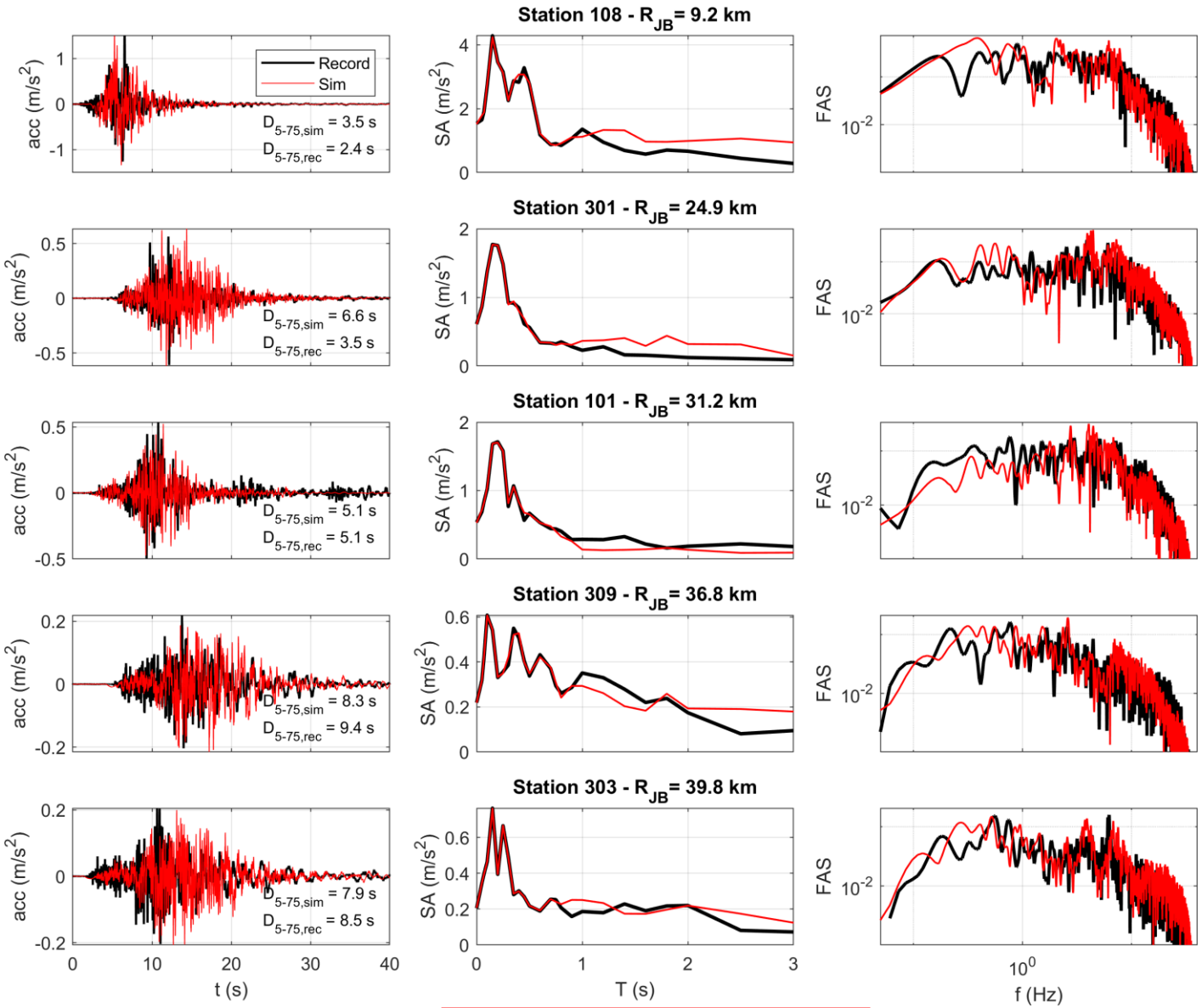
Paolucci et al. (2018), Hernández-Aguirre et al. (2026b)

Numerical model

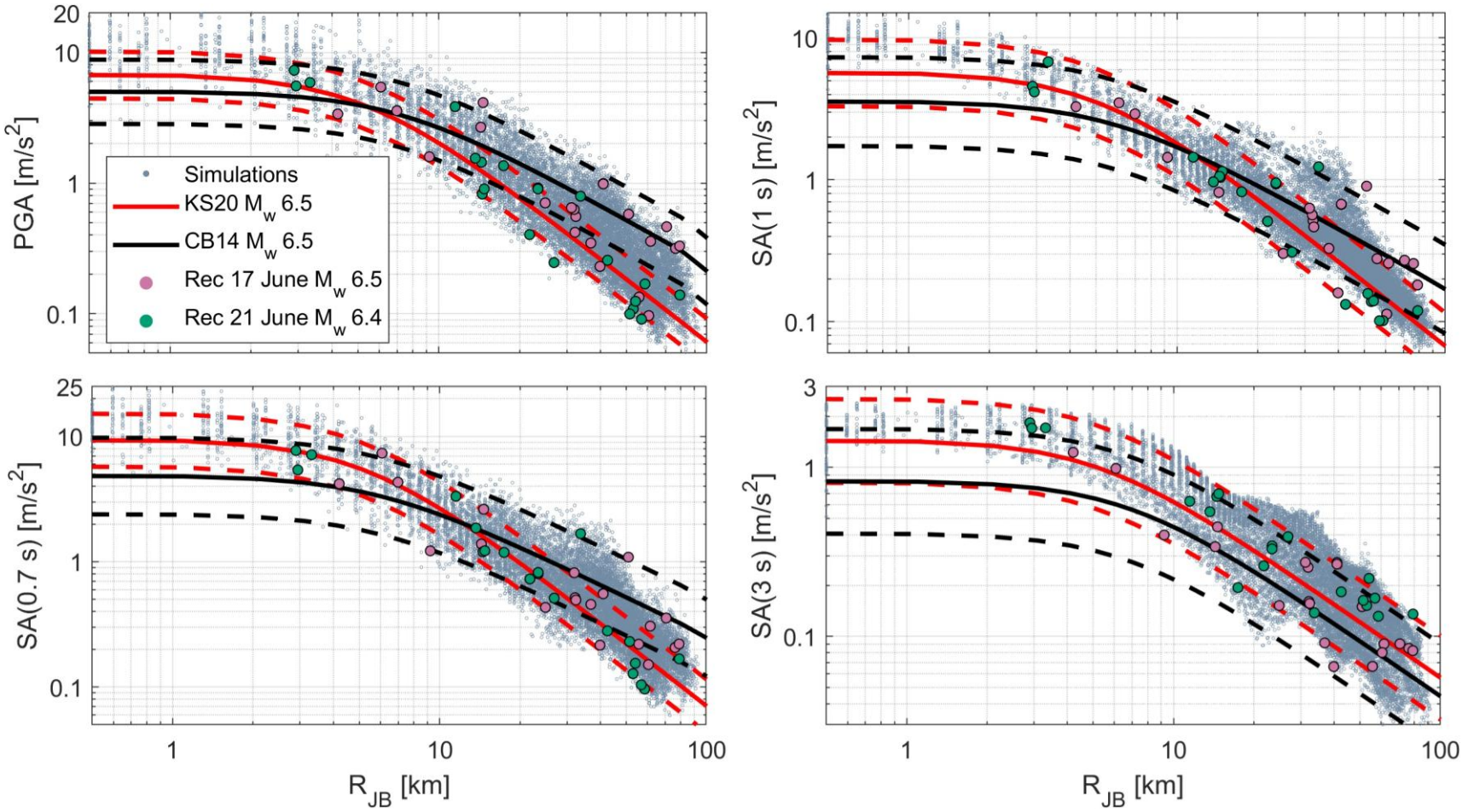


a) Adopted shear-wave velocity model. b) Three-dimensional mesh for South Iceland consisting of 1.67×10^6 spectral elements with spectral degree SD=3.

Broadband ground motions



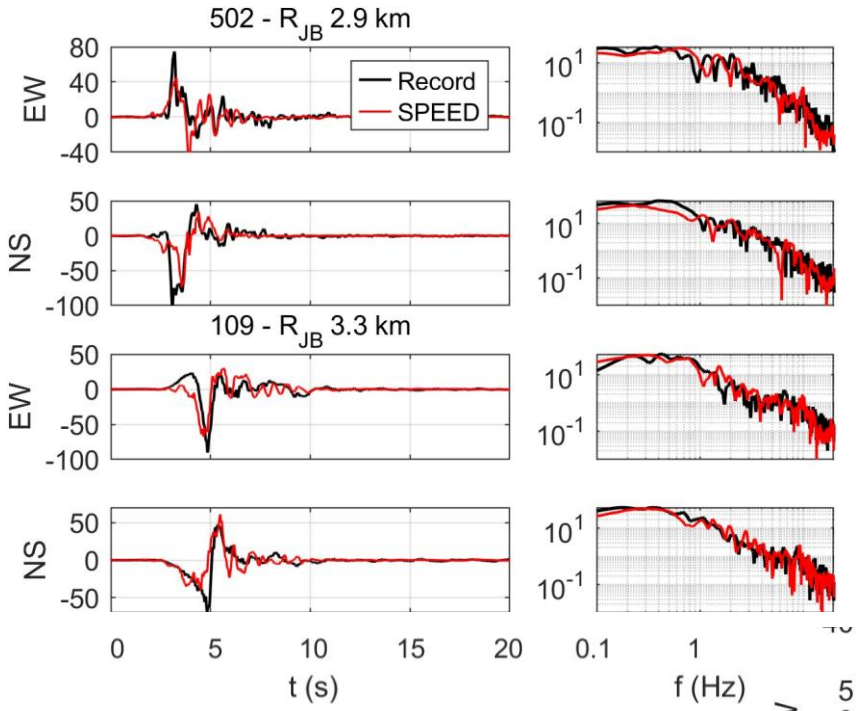
Ground-motion attenuation with distance

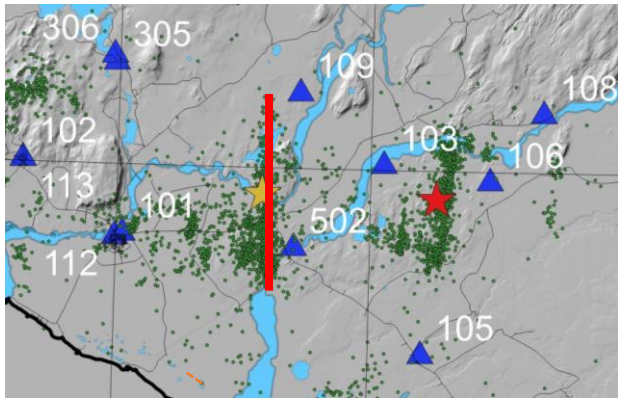


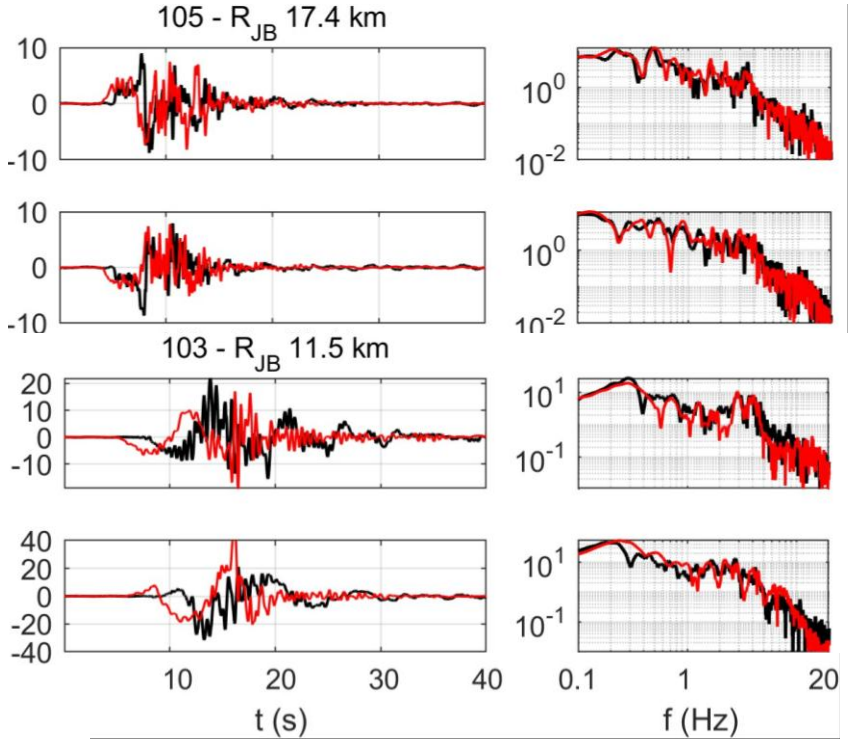
KS20 – Local GMM (Kowsari et al., 2020)

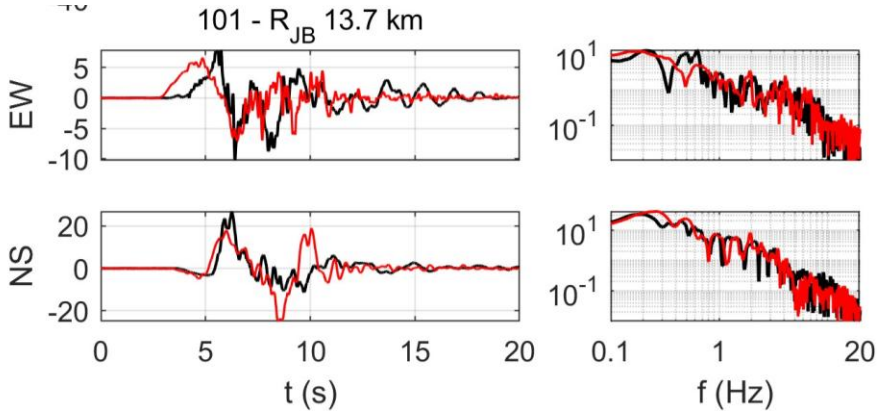
CB14 – NGA-West2 GMM (Campbell and Bozorgnia, 2014)

Near-fault ground motions



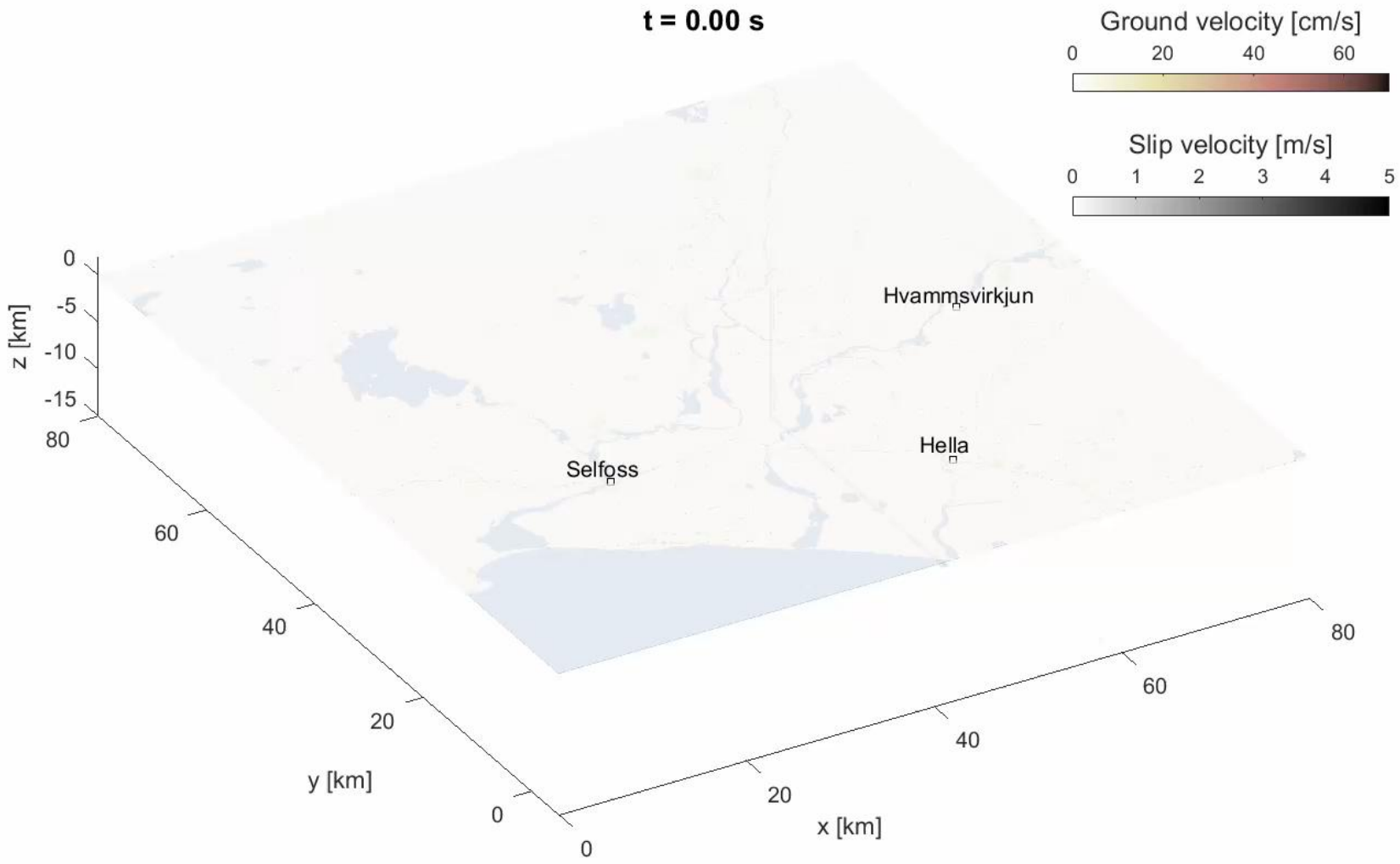




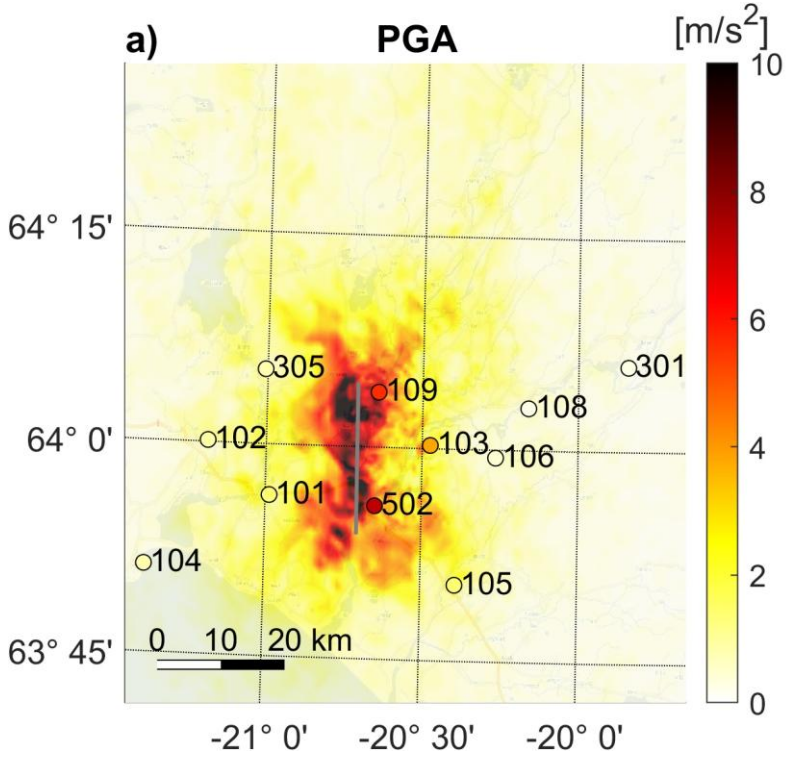


***Velocities in cm/s**

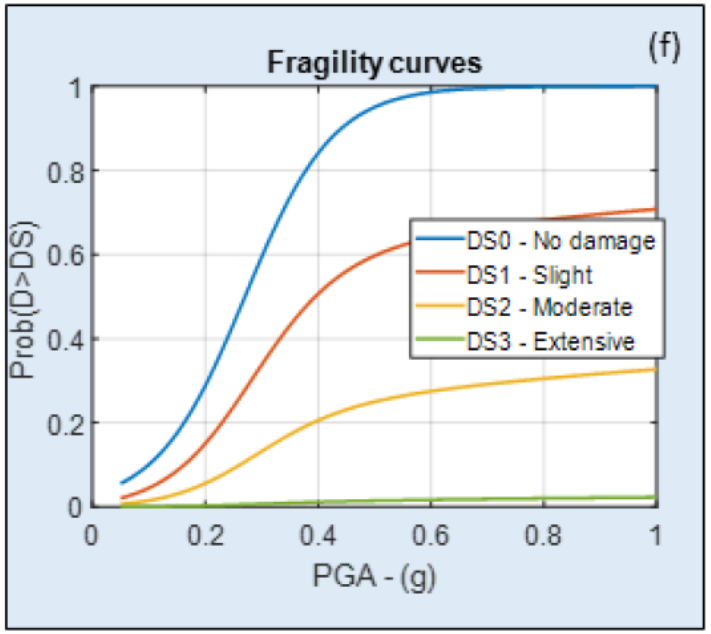
PBS Mw7 earthquake scenarios



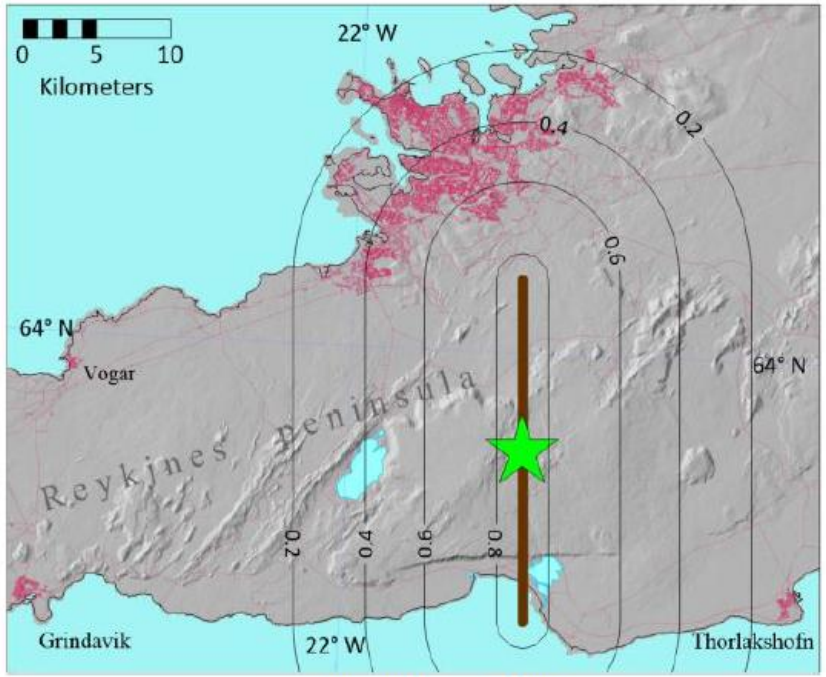
Damage scenarios



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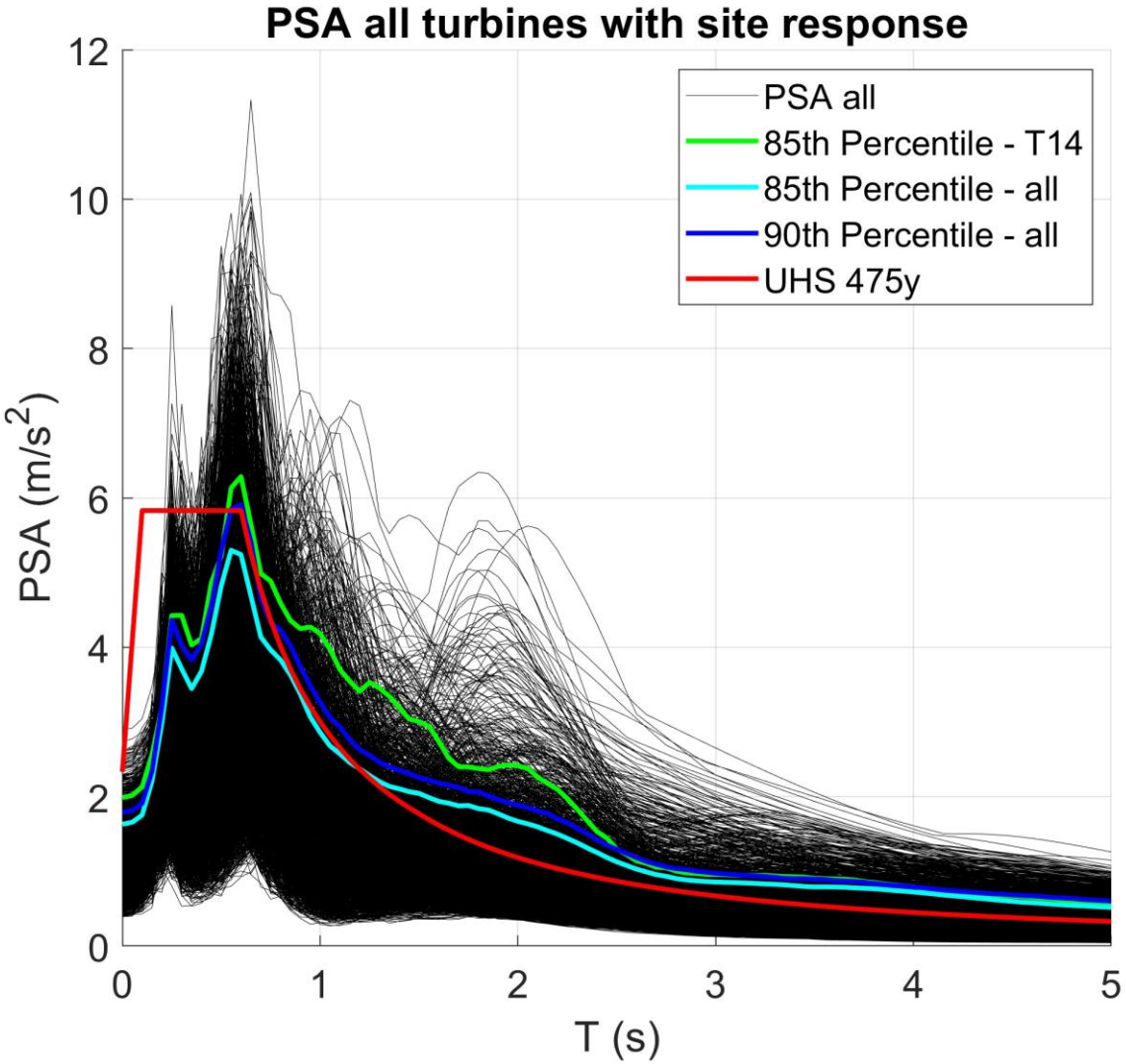


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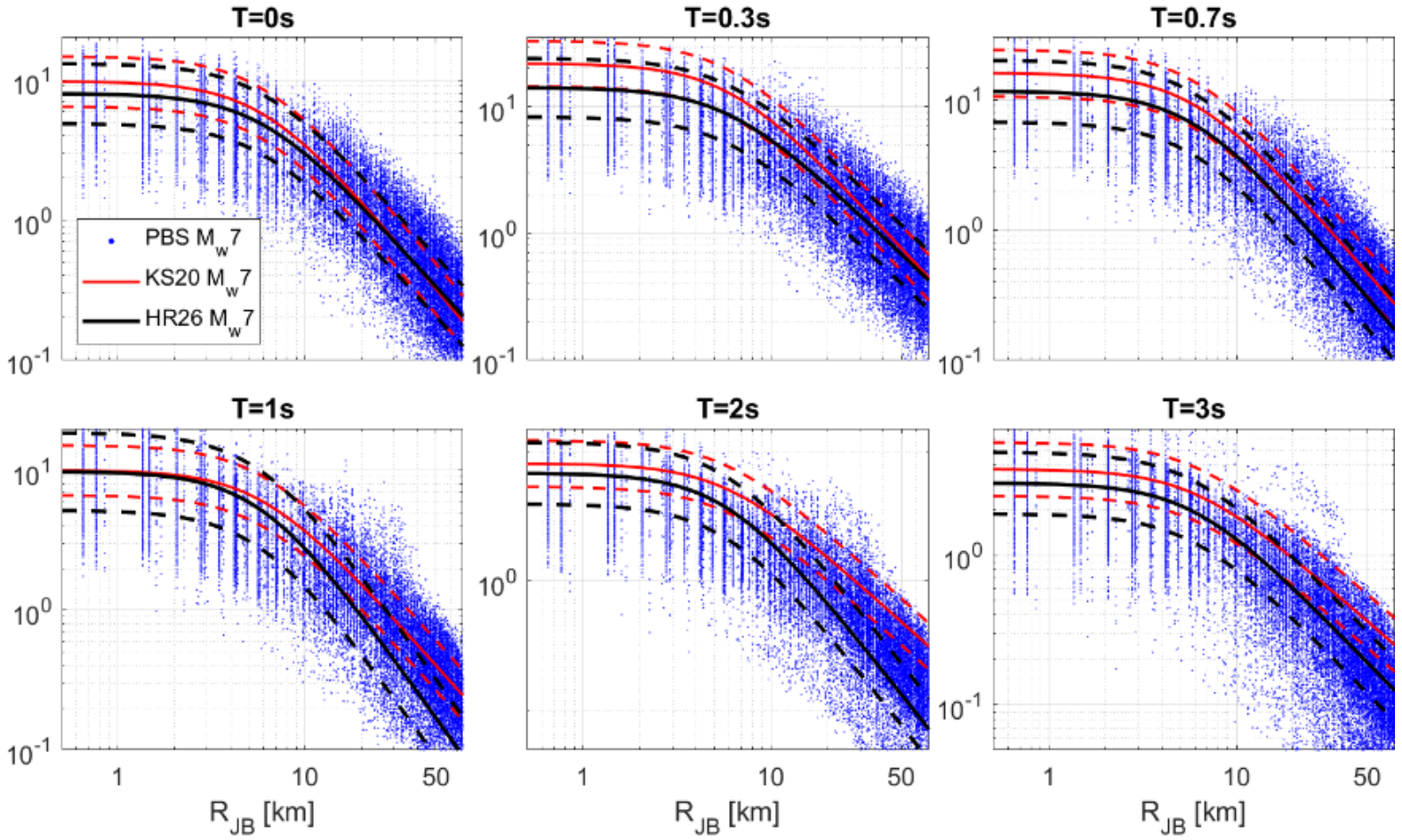


(a) Prob(D > DS0)

Site-specific seismic hazard assessment



Hybrid ground-motion model



1. **KS20 must extrapolate a scaling learned mainly from Mw ≤ 6.5.**
   The empirical data cannot strongly constrain large-magnitude saturation.

2. **Hybrid GMM,HR26, carries the scenario-simulations physics into the coefficient priors.**
   The magnitude-saturation term allows the posterior to depart from KS20 in the extrapolated domain.

Controlled extrapolation

Conclusions & future perspectives

- **Addressing data limitations:** Physics-based simulations (PBS) complement the limited strong-motion database in Iceland, enabling the investigation of large earthquakes beyond the recorded magnitude range.
- **Realistic earthquake scenarios:** By explicitly modelling fault rupture, seismic-wave propagation, and geological effects, PBS capture important features of the spatial distribution and variability of ground shaking.
- **Validation against observations:** Simulations of the 2000 South Iceland earthquakes demonstrate the ability of the framework to reproduce key characteristics of recorded ground motions.
- **Towards practical applications:** PBS can support earthquake damage scenarios, site-specific seismic hazard assessments, and the development of ground-motion models.

Key takeaway: *Physics-based simulations provide a bridge between our limited observations of past earthquakes and the assessment of future seismic scenarios.*

Vegagerðin

UNIVERSITY OF ICELAND

Takk fyrir mig

victorh@hi.is

Pseudo-dynamic rupture generator
Rupture parameters for Mw7 scenarios

