Ground-Shaking Prediction in the Era of Big Data

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4. Northumbria University, UK

Schatzalp Workshop 2025

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Universität Potsdam

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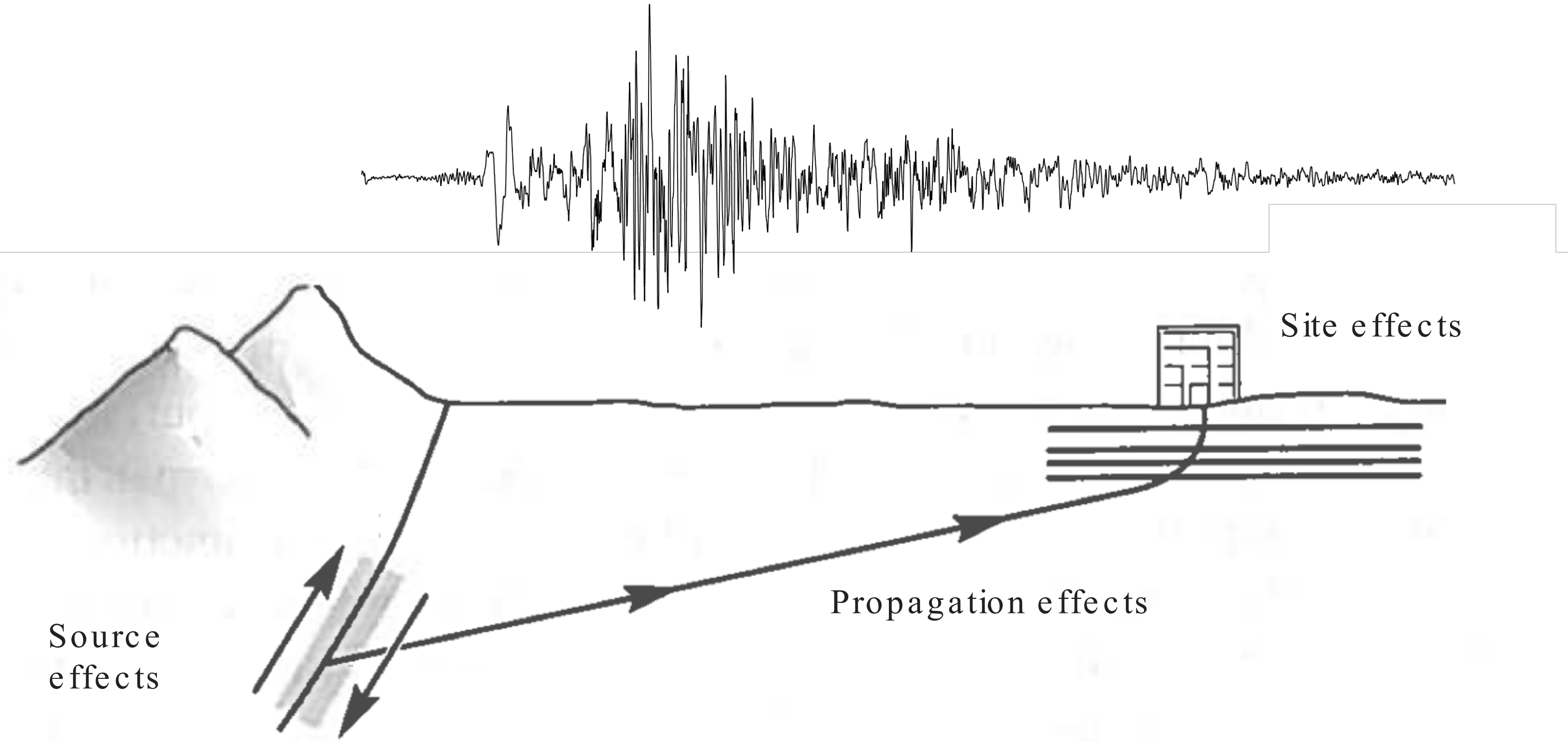
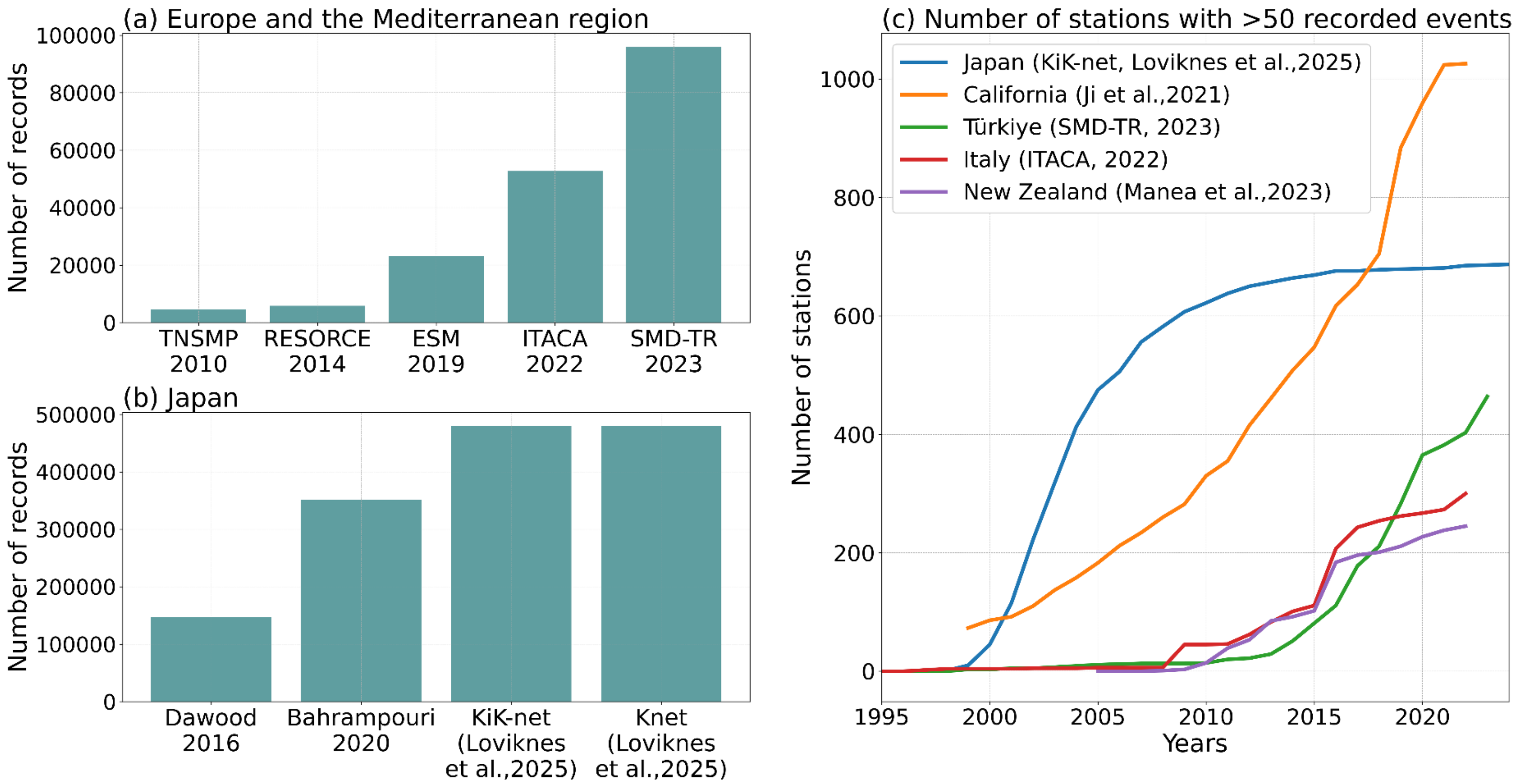
Shaking = source*path*site



Game changer: high - quality datasets: global

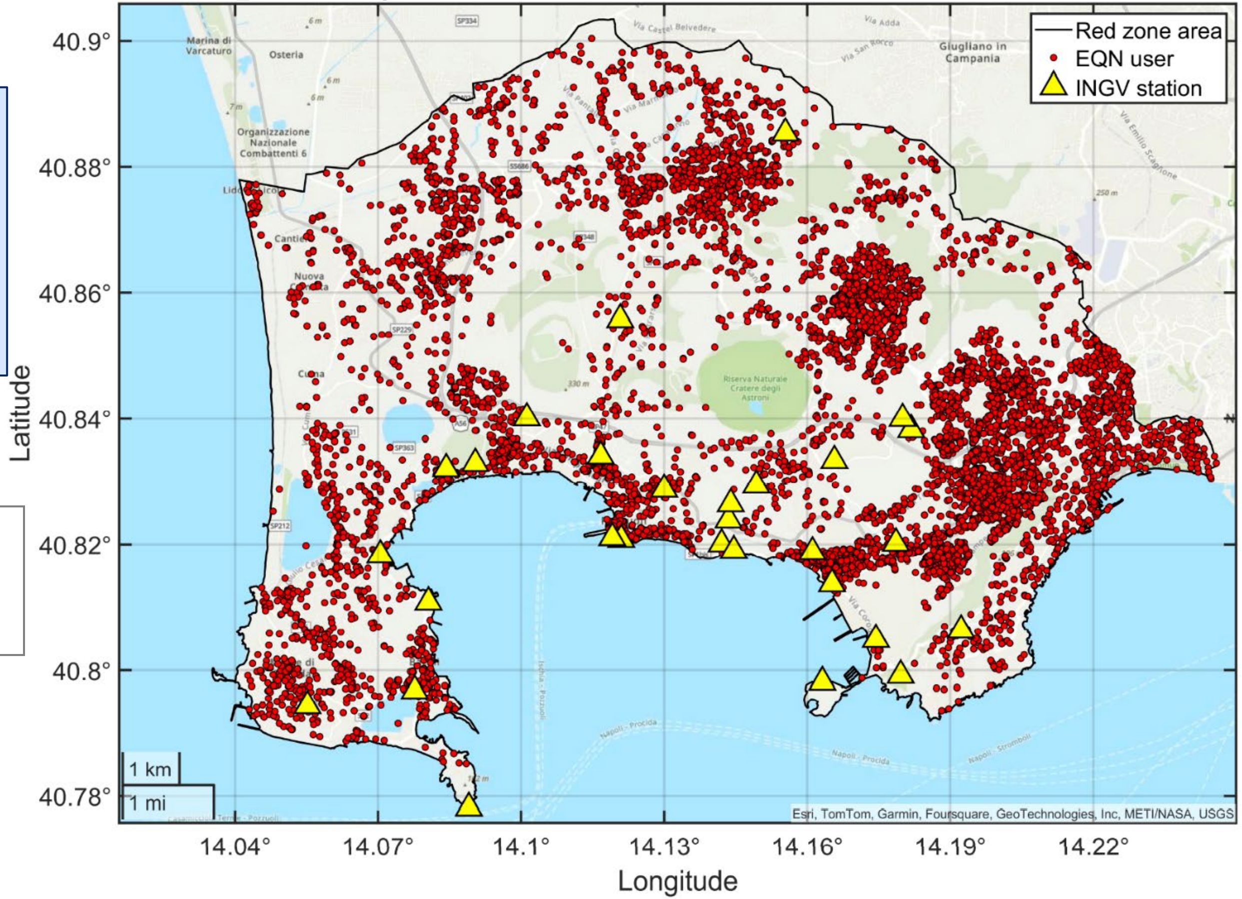


Game changers: high - quality datasets: local

Example of the red zone of Campi Flegrei

- Merging of seismological and crowdsourced smartphone data
- Uncertainties and peculiarities of each type of data integrated
- Mapping of spatial variations in seismic amplification

Finazzi F., Cotton F. and R. Bossu. Citizen's smartphones unravel earthquake shaking in urban areas. Submitted. https:// doi.org /10.21203/rs.3.rs -5886826/v1



How can we improve ground-shaking prediction with more data?

1. Calibration of local (linear) site-amplification models
2. From weak motion to strong motion
   - Calibration of non-linear models of soil behavior
   - Magnitude scaling of stress-drops
3. Frontiers
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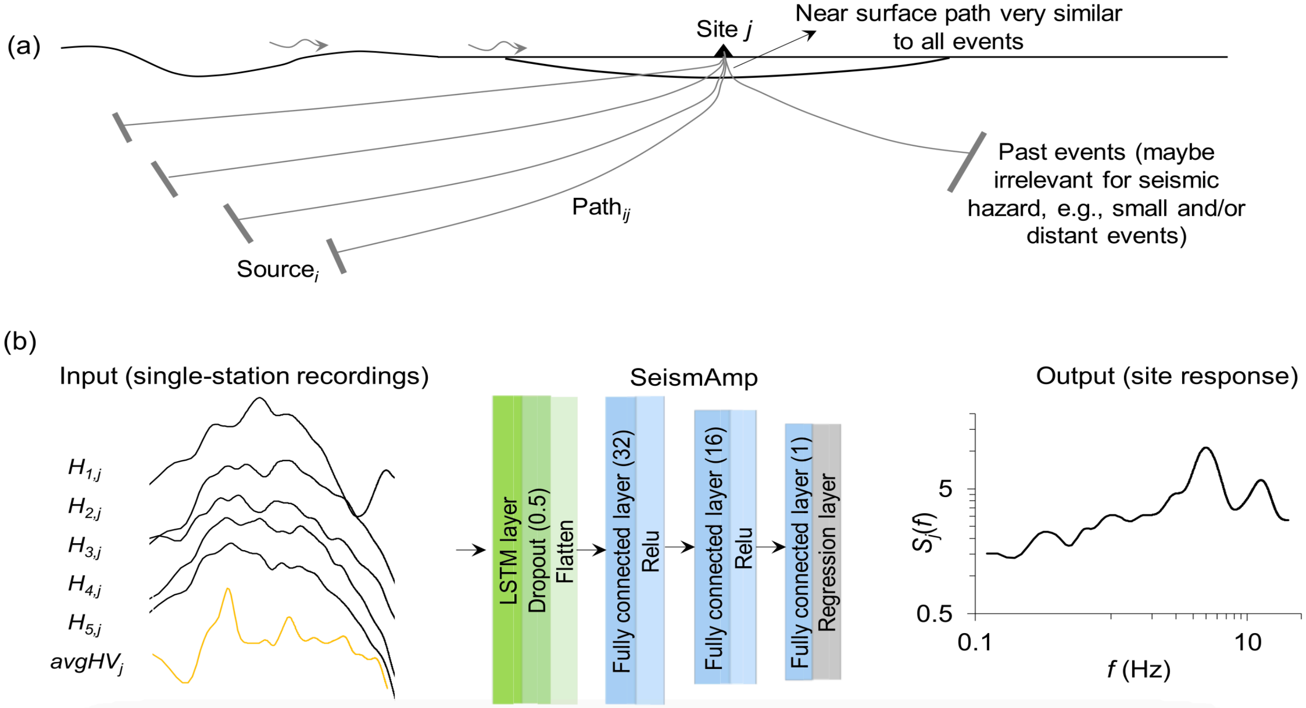
   - The high frequency frontier (attenuation): local records needed

Machine learning prediction of "linear" site response using single-station records (seisamp)



Zhu C, Cotton F, Kawase H, Bradley B (2023) Separating broad-band site response from single-station seismograms. Geophysical Journal International 234(3): 2053-2065

High resolution amplification map resulting from the analysis of both smartphones and seismological records

Finazzi F., Cotton F. and R. Bossu. Citizen's smartphones unravel earthquake shaking in urban areas. Submitted.
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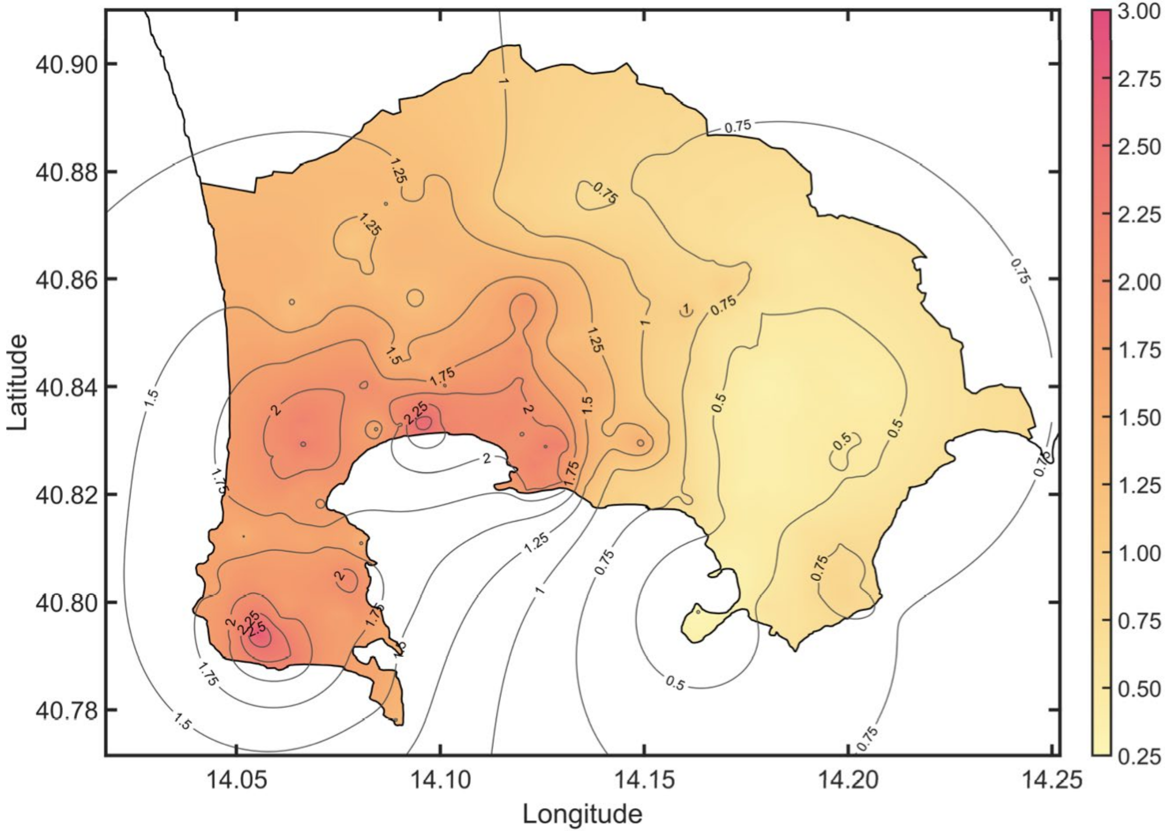

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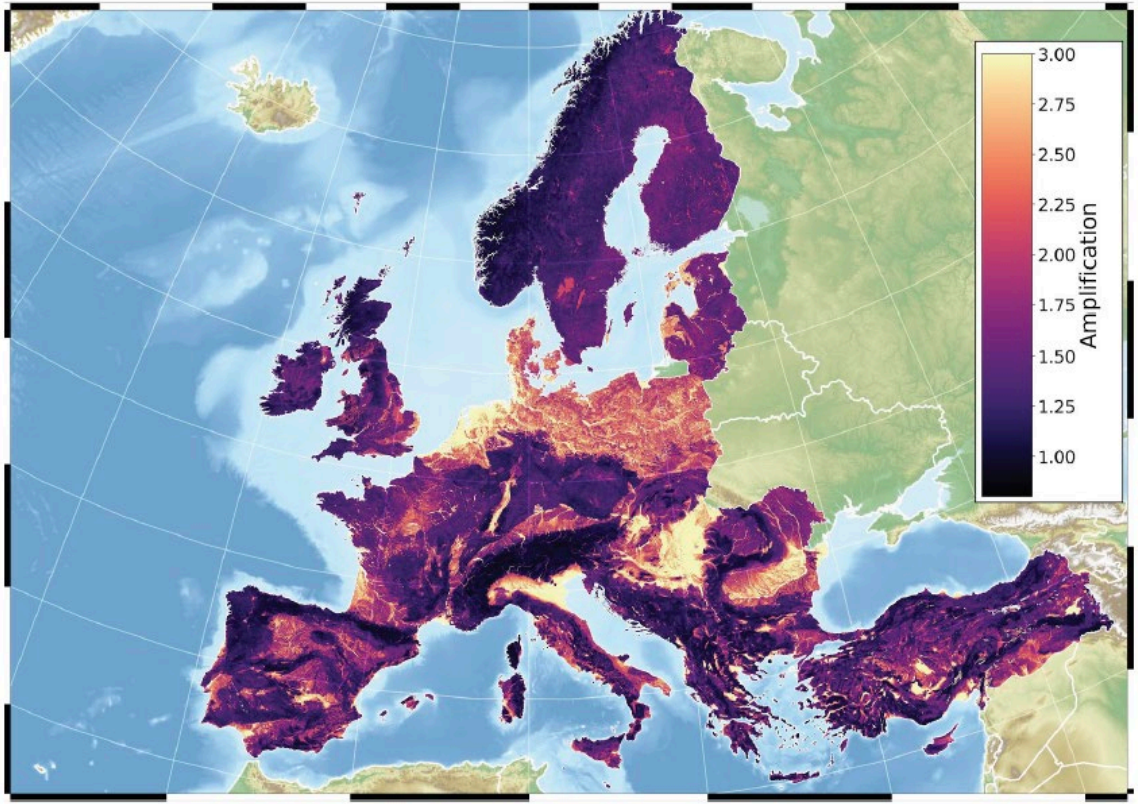
European amplification model based on slope and geology

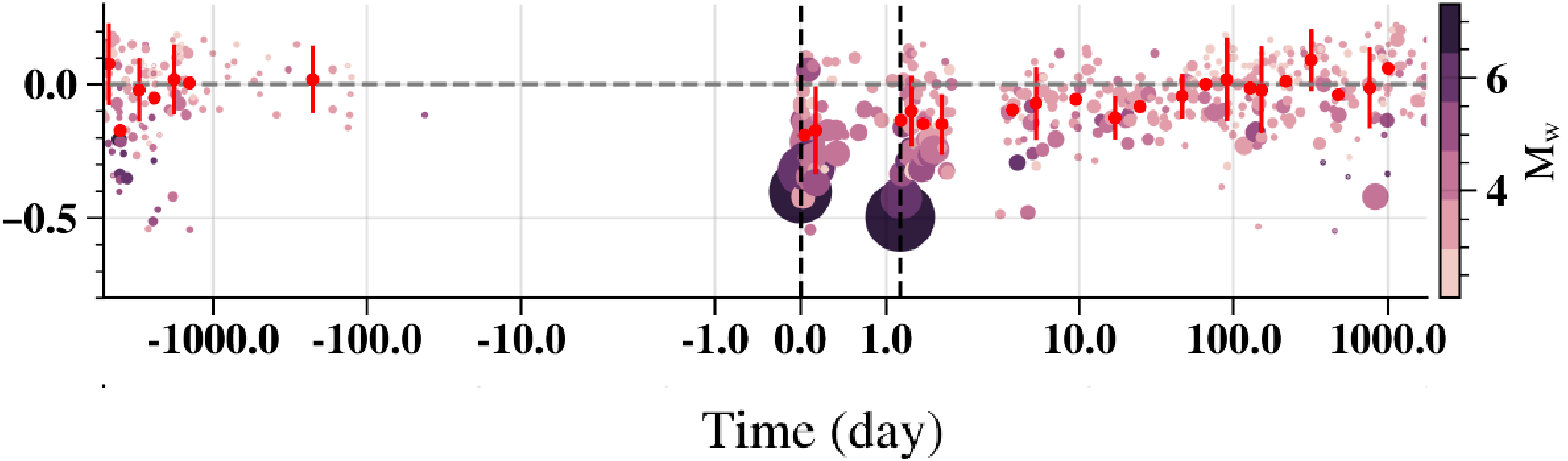


T = 1.0 s

Weatherill G, Crowley H, Roullé A, Tourlière B, Lemoine A, Gracianne C, Kotha SR, Cotton F (2023) Modelling site response at regional scale for the 2020 European Seismic Risk Model (ESRM20). Bulletin of Earthquake Engineering 21(2): 665-714

From weak motions to strong motions:

Velocity variation measured by autocorrelation at station KMMH 16 from 2002 to 2020 (Kumamoto Earthquake sequence)



Esfahani R, Cotton F, Bonilla LF (2024) Temporal variations of the 'in-situ' nonlinear behaviour of shallow sediments during the 2016 Kumamoto Earthquake sequence. Geophysical Journal International 238(3): 1626-1637.

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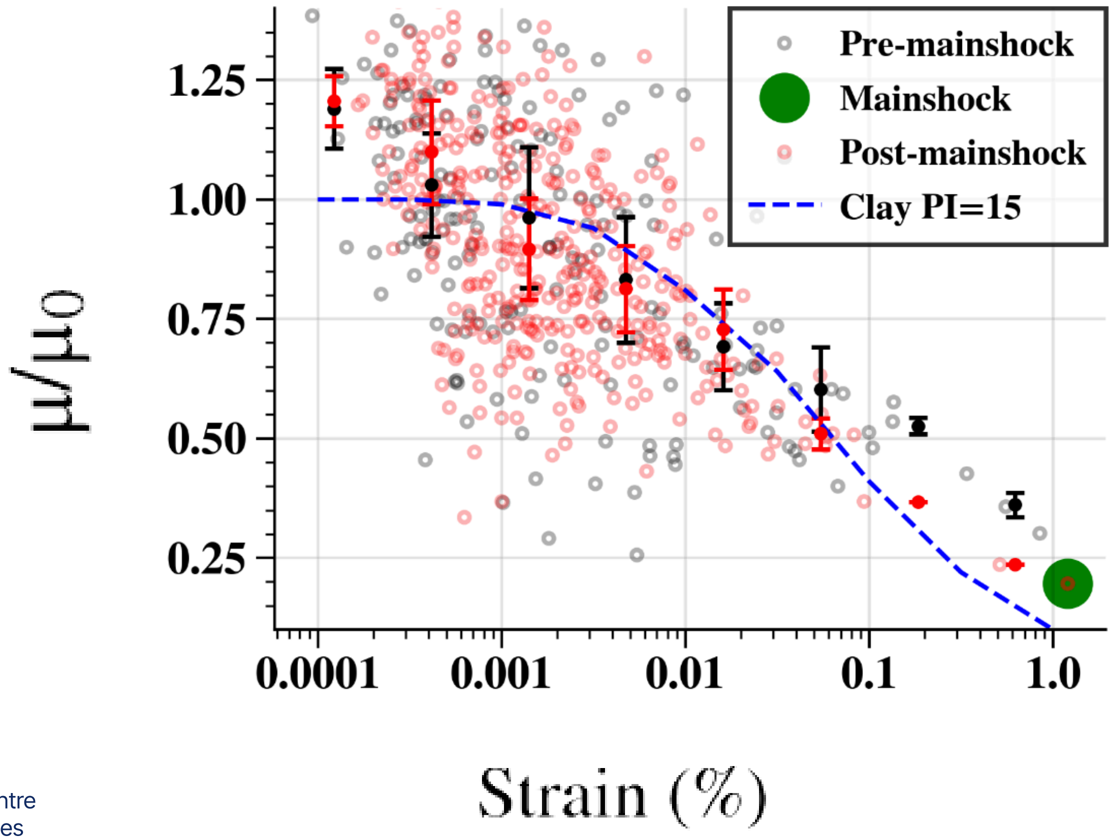
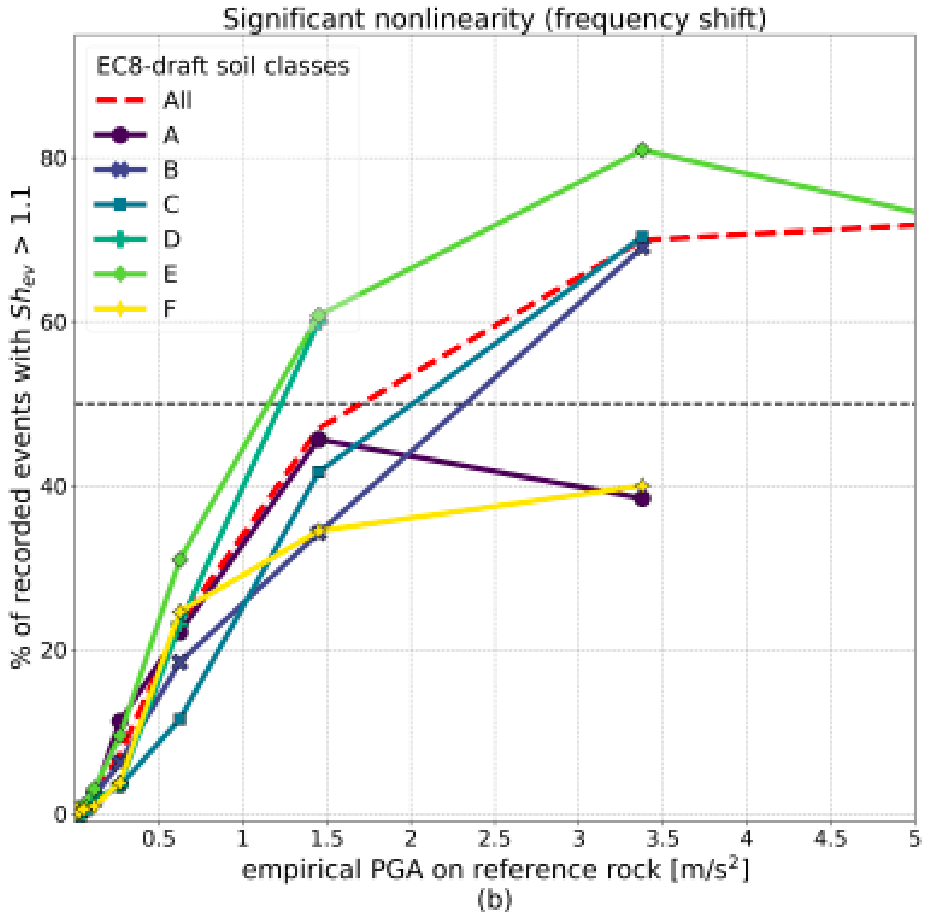
In situ relationship between shear-modulus and strain (PGV/vs30). A new way to calibrate non-linear models of soil behavior





Level of shaking producing "significant" non-linear effects for EC8 soil classes

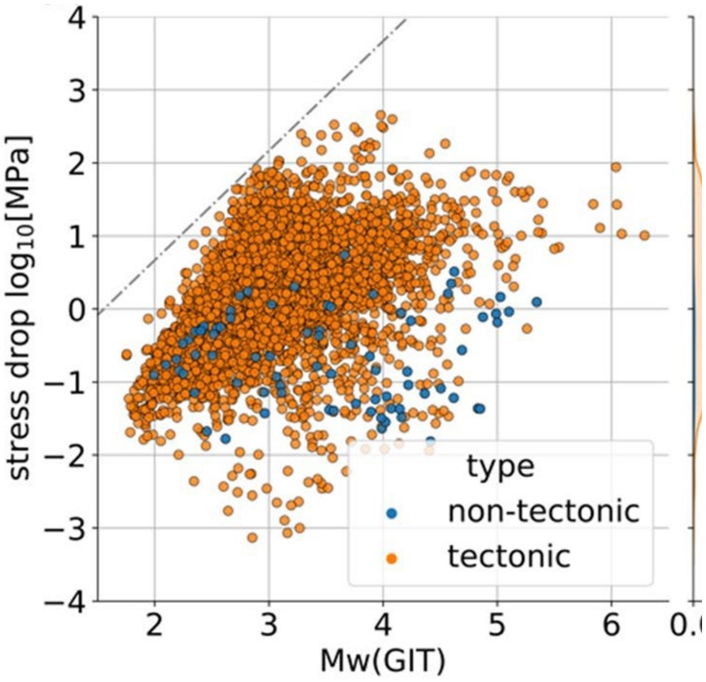
Ground class	Ground type	$V_{S,H}$ range
A	Very shallow: $Z_{S0.8} < 5\,\mathrm{m}$	$250\,\mathrm{m/s} \leq V_{S,H} < 800\,\mathrm{m/s}$
B	Shallow\intermediate: $5\,\mathrm{m} < Z_{S0.8} \leq 100\,\mathrm{m}$	$400\,\mathrm{m/s} \leq V_{S,H} < 800\,\mathrm{m/s}$
C	Intermediate: $30\,\mathrm{m} < Z_{S0.8} \leq 100\,\mathrm{m}$	$250\,\mathrm{m/s} \leq V_{S,H} < 400\,\mathrm{m/s}$
D	Intermediate: $30\,\mathrm{m} < Z_{S0.8} \leq 100\,\mathrm{m}$	$150\,\mathrm{m/s} \leq V_{S,H} < 250\,\mathrm{m/s}$
E	Very shallow\shallow: $Z_{S0.8} < 30\,\mathrm{m}$	$150\,\mathrm{m/s} \leq V_{S,H} < 400\,\mathrm{m/s}$
F	Intermediate\deep: $Z_{S0.8} > 100\,\mathrm{m}$	$150\,\mathrm{m/s} \leq V_{S,H} < 400\,\mathrm{m/s}$

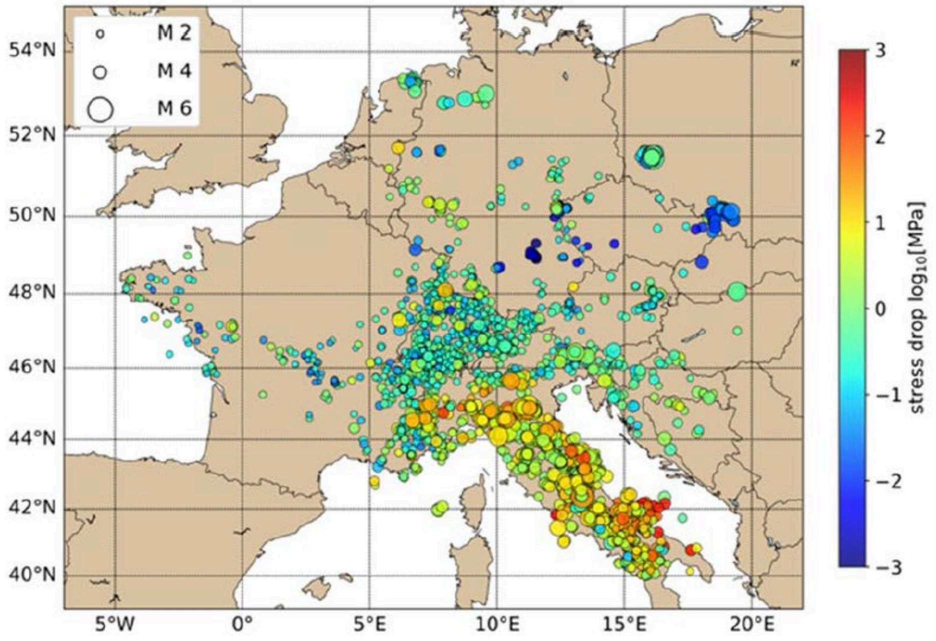
High variability from one station to another within the same site class

Loviknes , K., Bergamo, P., Fäh, D., and Cotton, F. (2024). Systematic assessment (1997 - 2024) of nonlinear soil behaviour at KiK-NET sites in Japan. thresholds and controlling site factors. Earthquake Spectra, in press

From weak motion to strong-motion:

Variation of stress-drop with magnitude (Western-Europe, 1990-2020)





Yen M-H, Bindi D, Oth A, Edwards B, Zaccarelli R, Cotton F (2024) Source parameters and scaling relationships of stress drop for shallow crustal seismic events in Western Europe. Journal of Seismology 28: 63-79.

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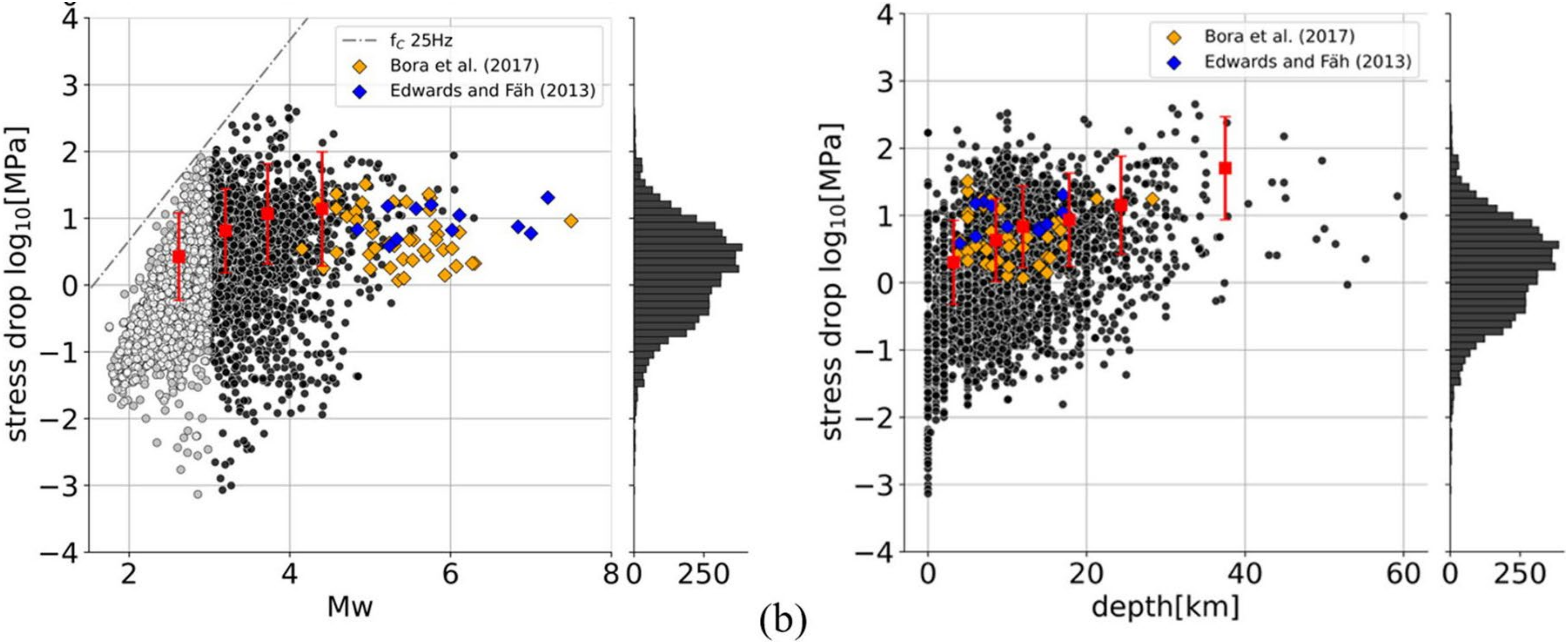
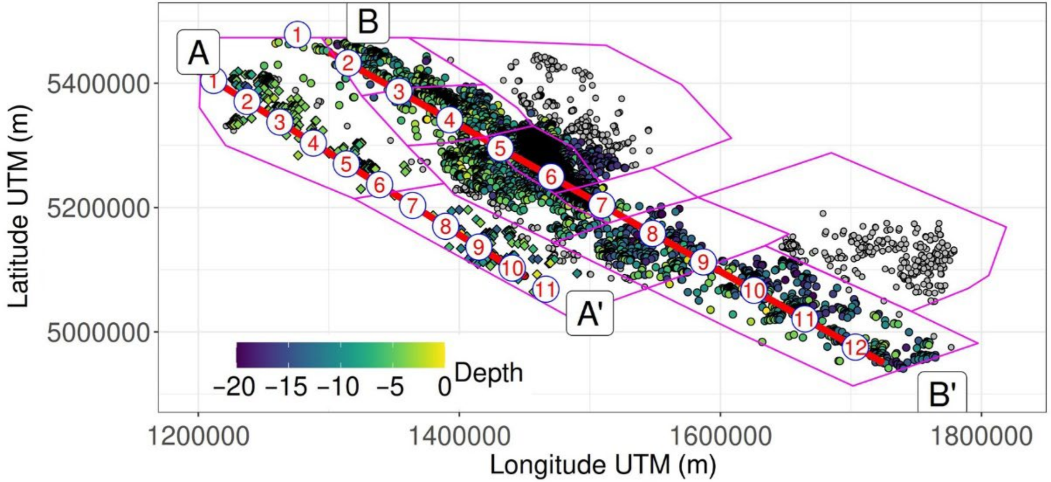
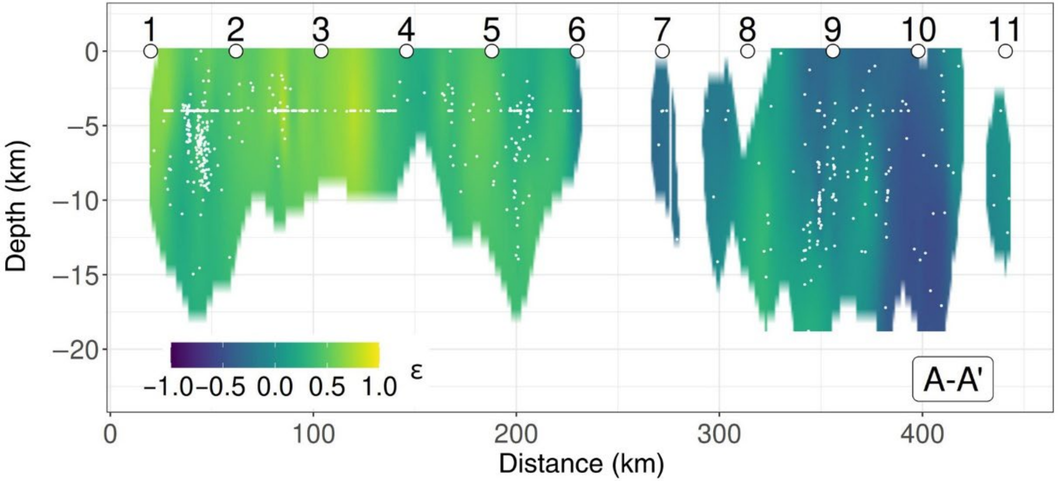
Variation of stress - drop with magnitude and depth



Yen M-H, Bindi D, Oth A, Edwards B, Zaccarelli R, Cotton F (2024) Source parameters and scaling relationships of stress drop for shallow crustal seismic events in Western Europe. Journal of Seismology 28: 63 - 79.

Variation of stress -drop with depth (central Italy)

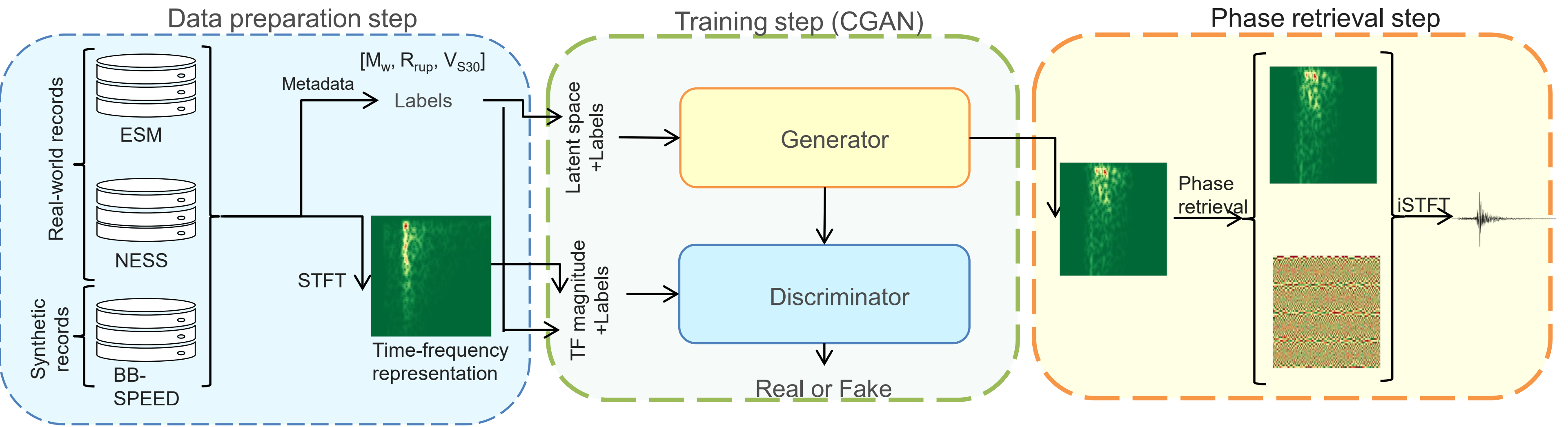




Bindi, D., Spallarossa, D., Picozzi, M., & Tarchini, G. (2024). Scaling and Depth Variability of Source Parameters in Central and Southern Italy Using Regional Attenuation Models. Bulletin of the Seismological Society of America

Machine -learning -based simulation of time histories

Model Conditioned on parameters [Mw, R, Vs30]

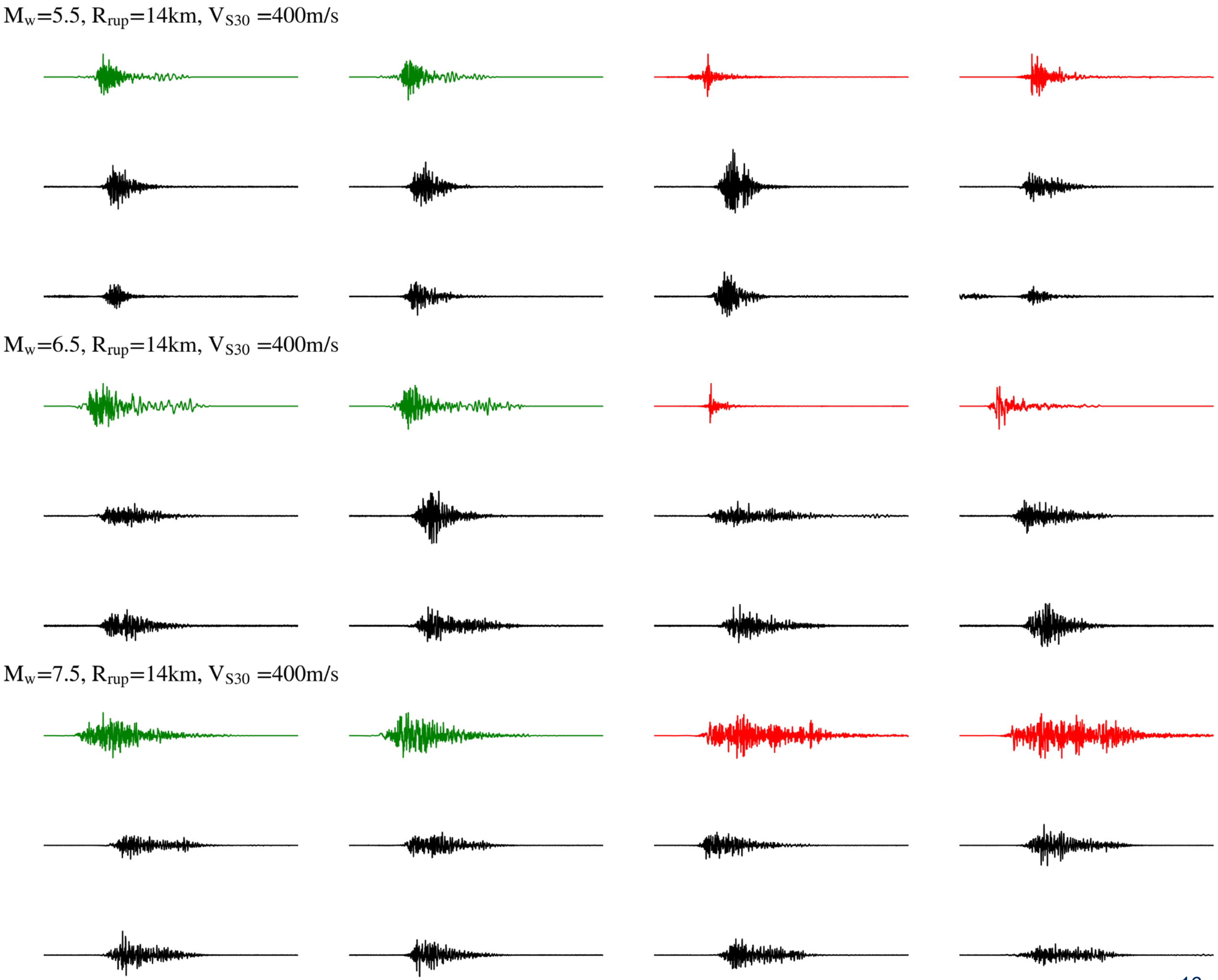


TFCGAN: Time-Frequency Conditional Generative Adversarial network

Esfahani R, Cotton F, Ohrnberger M, Scherbaum F (2023) TFCGAN: Nonstationary Ground-Motion Simulation in the Time–Frequency Domain Using Conditional Generative Adversarial Network (CGAN) and Phase Retrieval Methods. Bulletin of the Seismological Society of America 113(1): 453-467.

Florez, MA, Caporale M, Buabthong P, Ross ZE, Asimaki D, Meier M (2022) Data-driven synthesis of broadband earthquake ground motions using artificial intelligence, Bulletin of the Seismological Society of America 112(4): 1979-1996.

Time-domain simulations input=M, R, Vs30

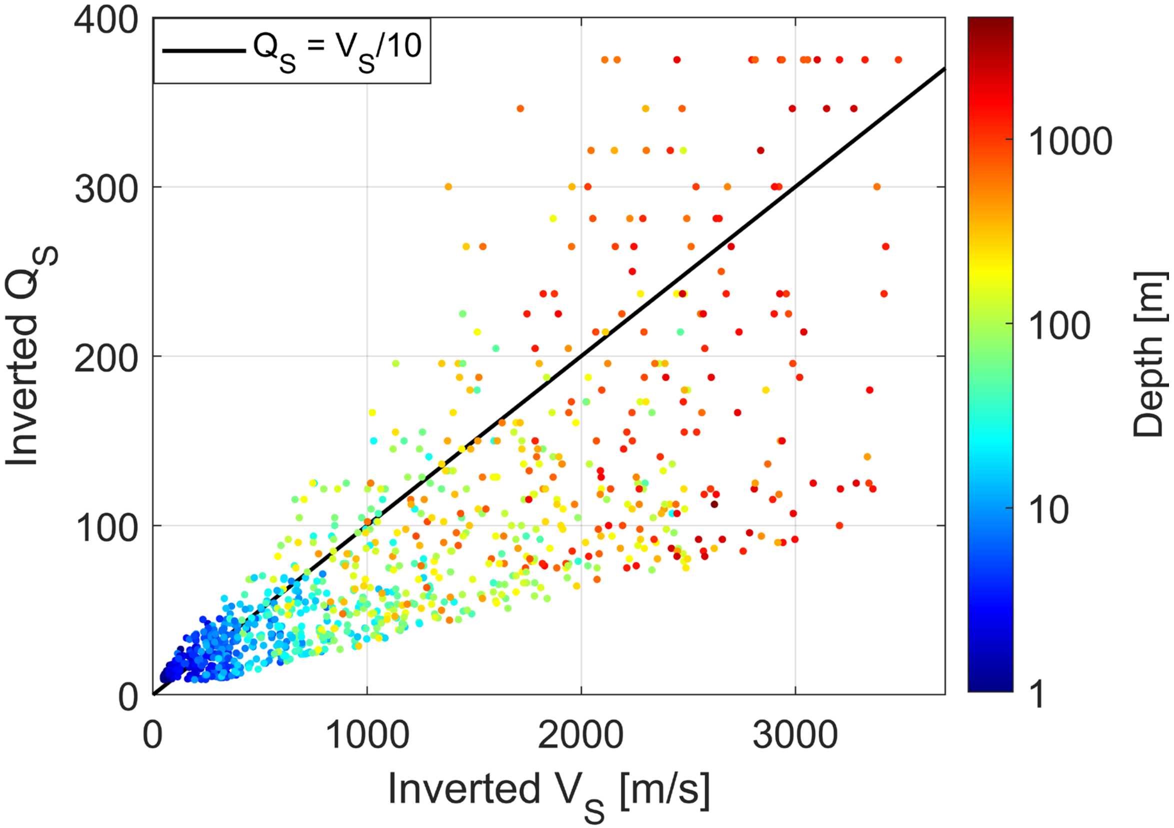


- Physic-based simulation
- Real data
- TFCGAN simulation

Esfahani et al. (in preparation)

Quality factors and attenuation are highly site specific (on site records needed)

Pilz, M., Cotton, F., & Zhu, C. (2025). Site-response high -frequency frontiers and the added value of site -specific earthquake record -based measurements of velocity and attenuation. Earthquake Spectra, 87552930241311312 .



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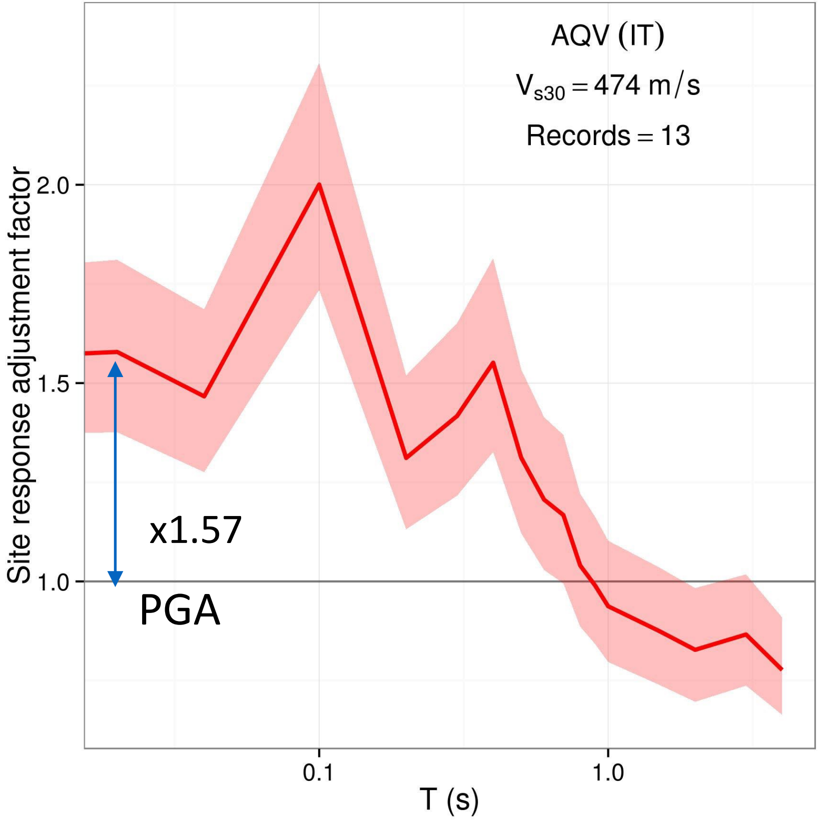
Site specific amplification (site term)

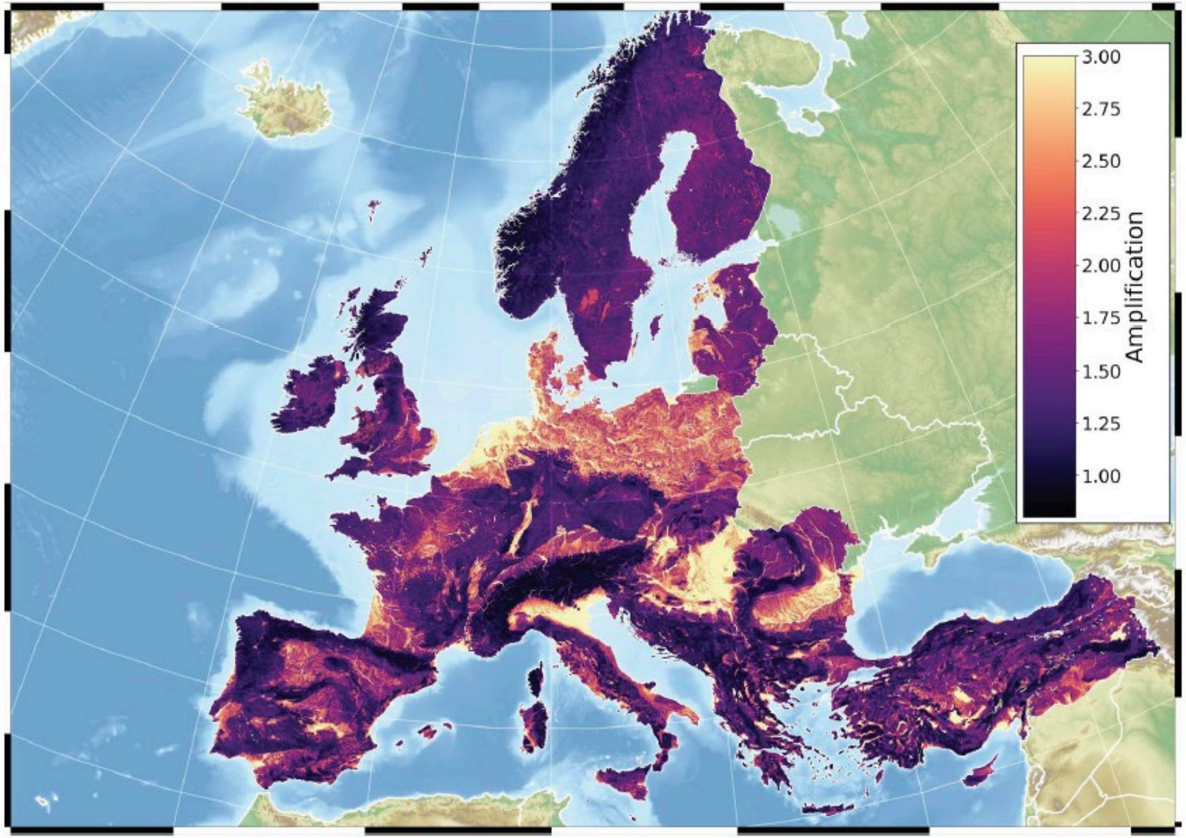


$$ln(GM_{es}) = F_M(M) + F_R(R, M) + \delta S2S_s + \delta B_e + \delta WS_{es}$$

Example of the site term at the station AQV Aquila Italy (13 records)

Kotha SR, Bindi D, Cotton F (2017) From Ergodic to Region - and Site - Specific Probabilistic Seismic Hazard Assessment: Method Development and Application at European and Middle Eastern Sites. Earthquake Spectra 33(4): 1433 - 1453

European amplification model based on slope and geology



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Graeme Weatherill

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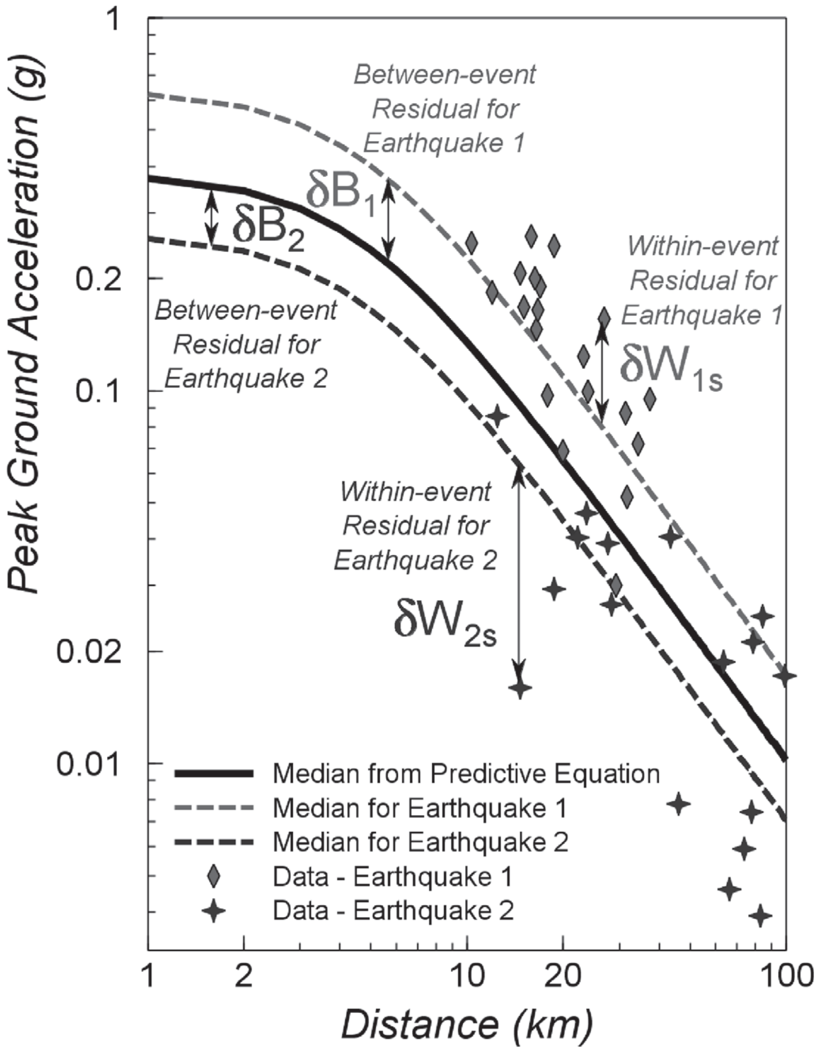

Method: data - analysis, partitioning and quantification

- = Between-event residual: earthquake is more or less energetic than average for the source properties (M, SoF, depth etc.)
- = Within-event residual: ground motion at sites higher/lower than expected given the distance and site properties

Al Atik L, Abrahamson N, Bommer JJ, Scherbaum F, Cotton F, Kuehn N (2010) The Variability of Ground-Motion Prediction Models and Its Components. Seismological Research Letters 81(5): 794-801.

Game changers: high-quality datasets