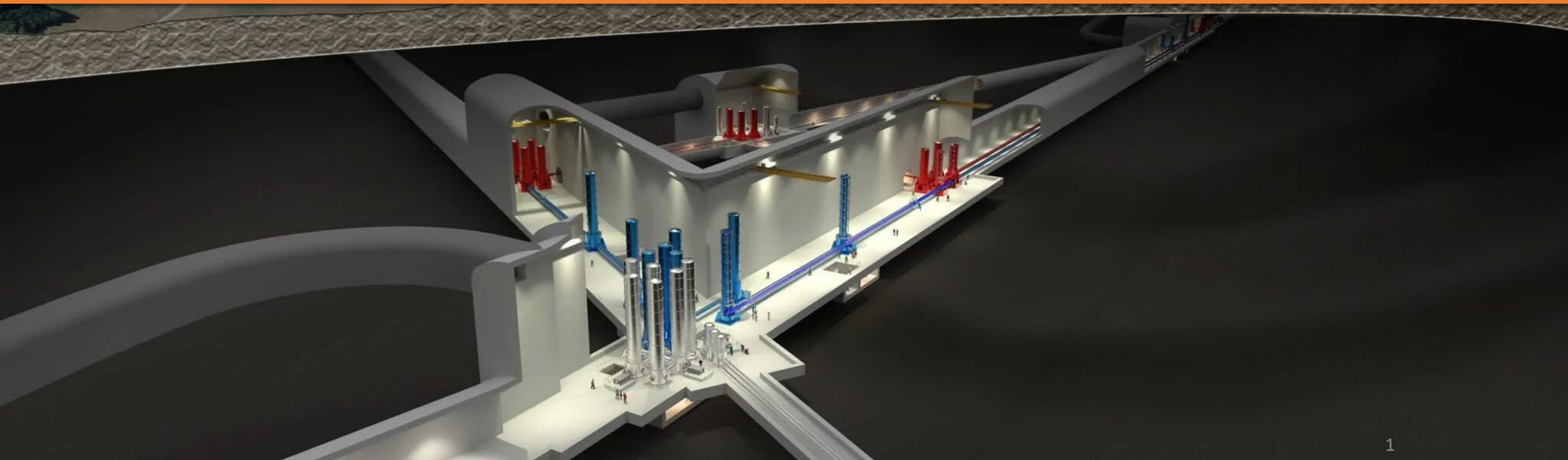
Seismic Newtonian Noise Modeling

for Einstein Telescope: Progress Report

Luqian Jiang | Gran Sasso Science Institute | April 2026



Outline

1. Sardinia Candidate Site - Overview
2. Computational Challenges in SNN Modeling
3. Seismic Noise Simulation with Random Ambient-Noise Sources
4. Conclusions and Outlook

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1 Sardinia Candidate Site - Overview

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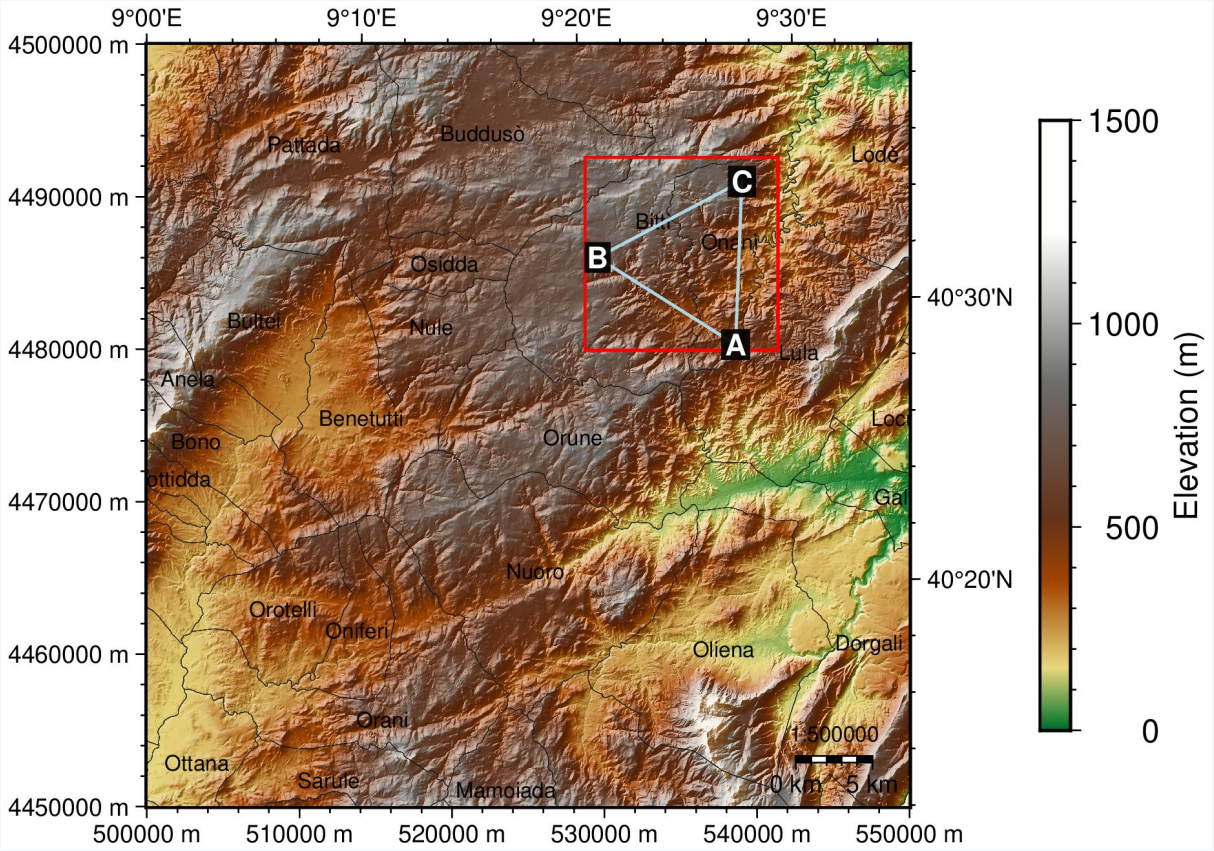
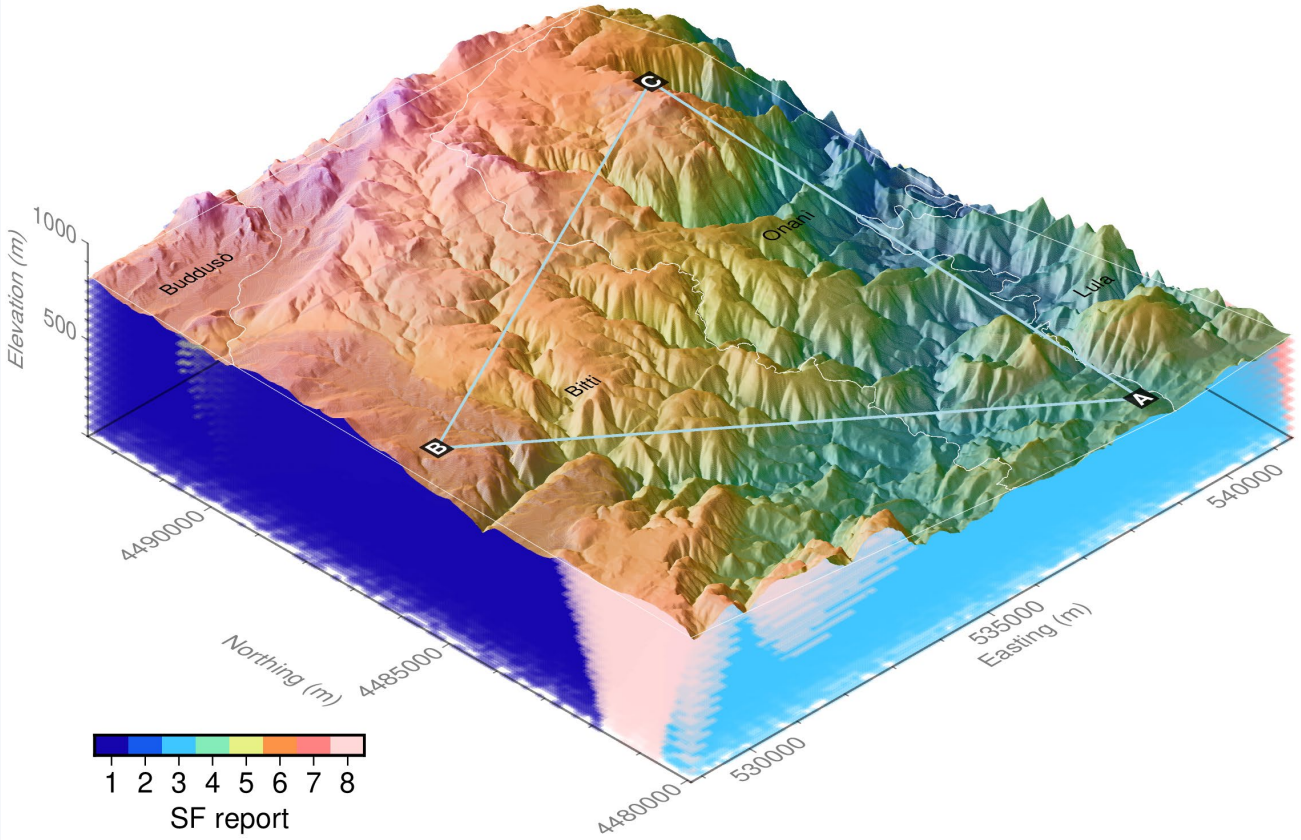
The Sardinia Candidate Site for Einstein Telescope

Sardinia has been identified as a leading candidate site for ET, owing to its low seismic noise levels and favourable geological conditions for underground construction.





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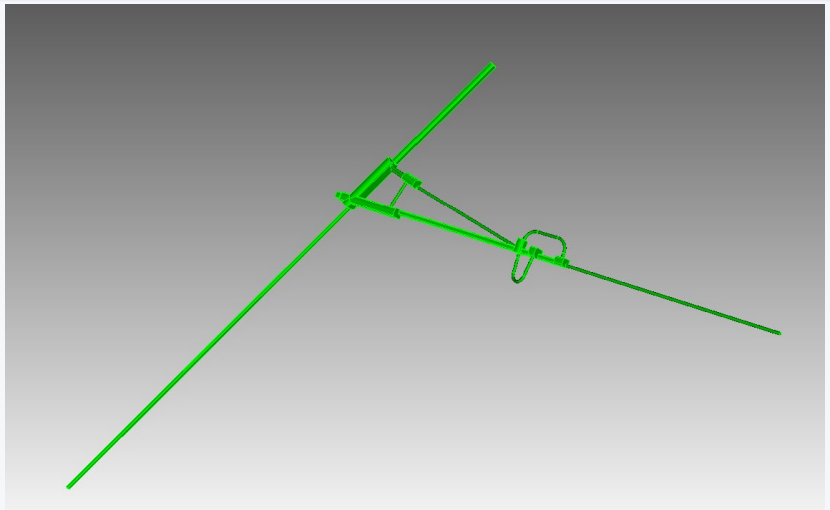
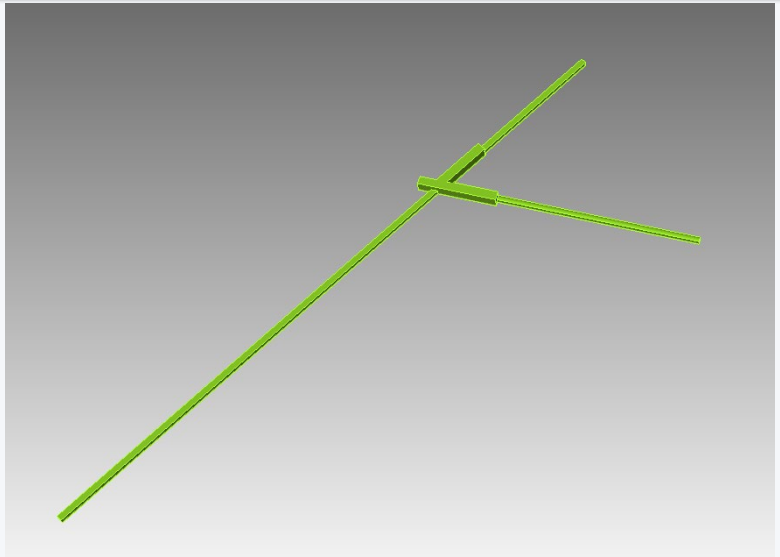
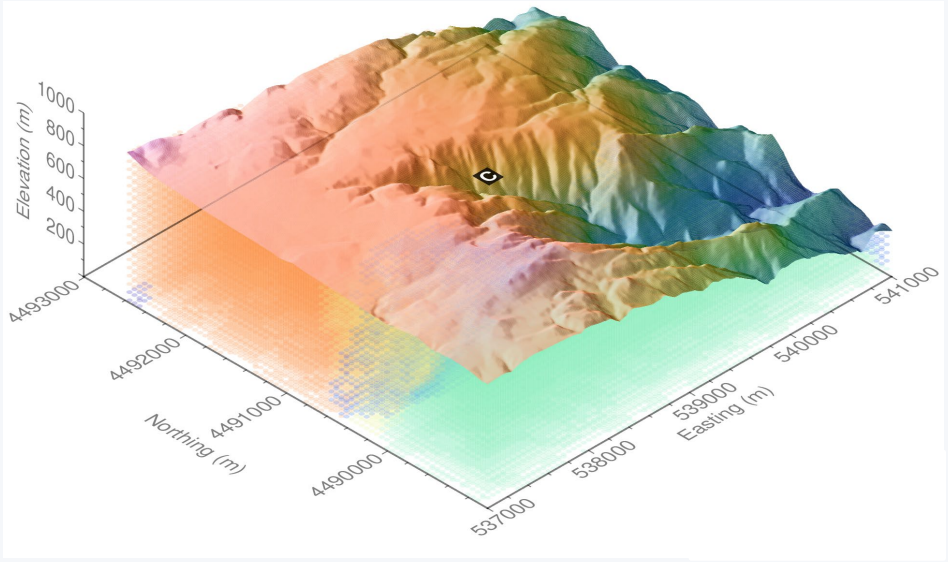
Simplified Cavern and Meshing



Simplify the cavern

removing some minor and mesh-unfriendly features

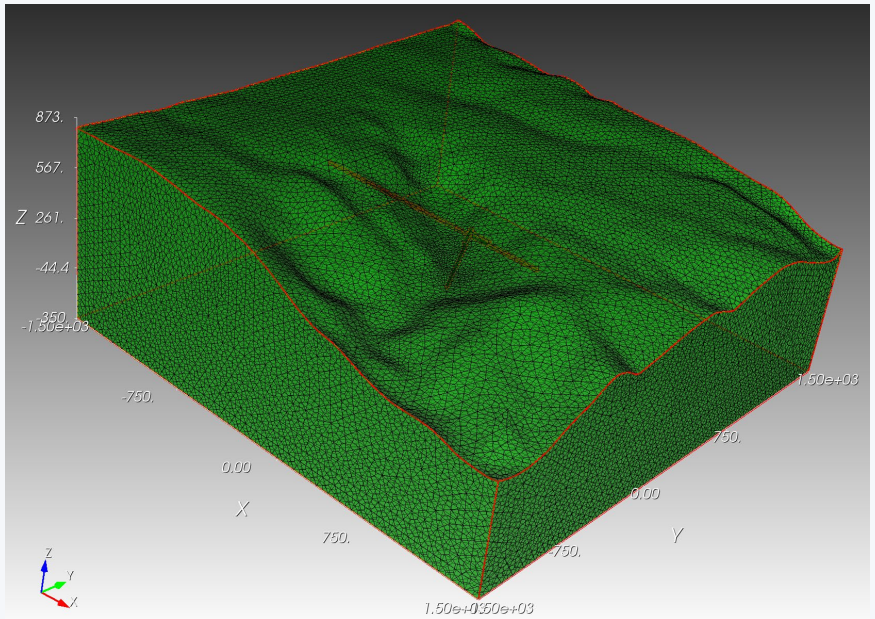




Meshing

(Cubit)

SPECFEM3D



SNN Simulation — The Challenge

Computational Cost Driven by Cavern

- Explicit meshing of the underground cavern introduces irregular geometries with locally refined mesh elements (dh_{min}).
- Governed by the CFL stability condition ($dt \propto \frac{dh_{min}}{vp_{max}}$), this severely restricts the time step, making forward simulations computationally expensive.

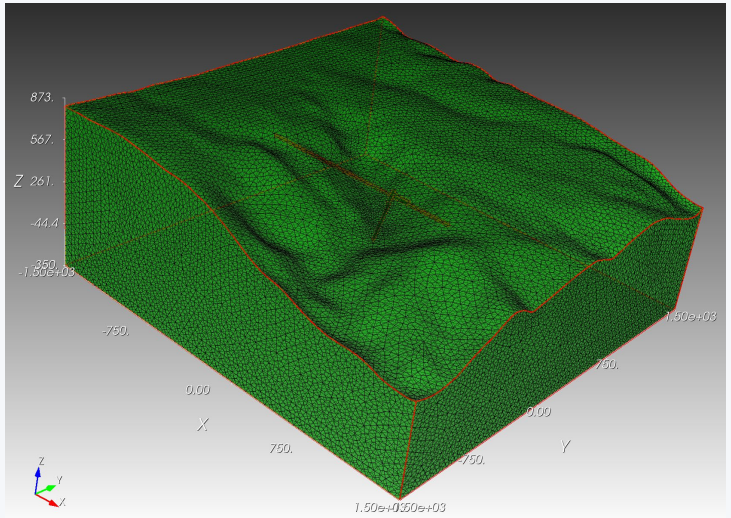
High Spatial Resolution Required for SNN Estimation

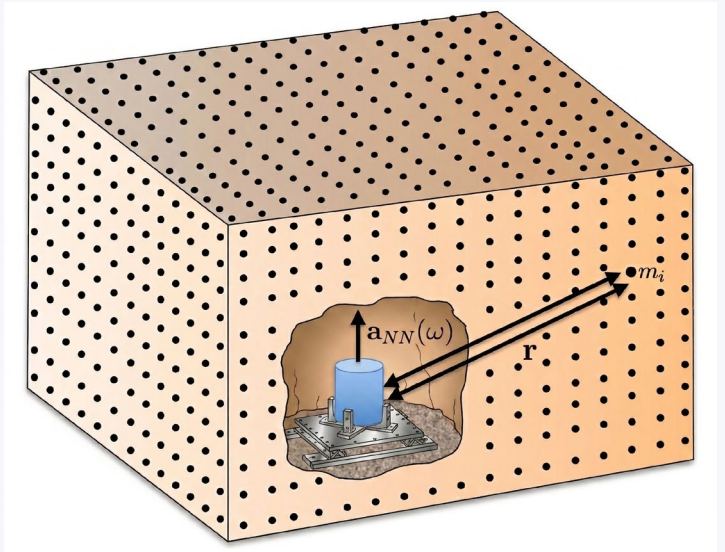
- SNN estimation requires evaluating the seismic correlation volume integral around the test mass, with dense spatial sampling near the cavern to resolve scattering-induced contributions.

Scalability Bottleneck in Adjoint-Based CC Computation

- In the adjoint method used in Andric and Harms (2020), the cross-correlation between each main receiver and auxiliary sensors is computed via an independent simulation. The total computational cost therefore scales linearly with the number of main receivers, posing a significant challenge for large-scale seismometer arrays.

We need a simulation approach that yields all necessary CPSDs without running a separate simulation for each receiver.





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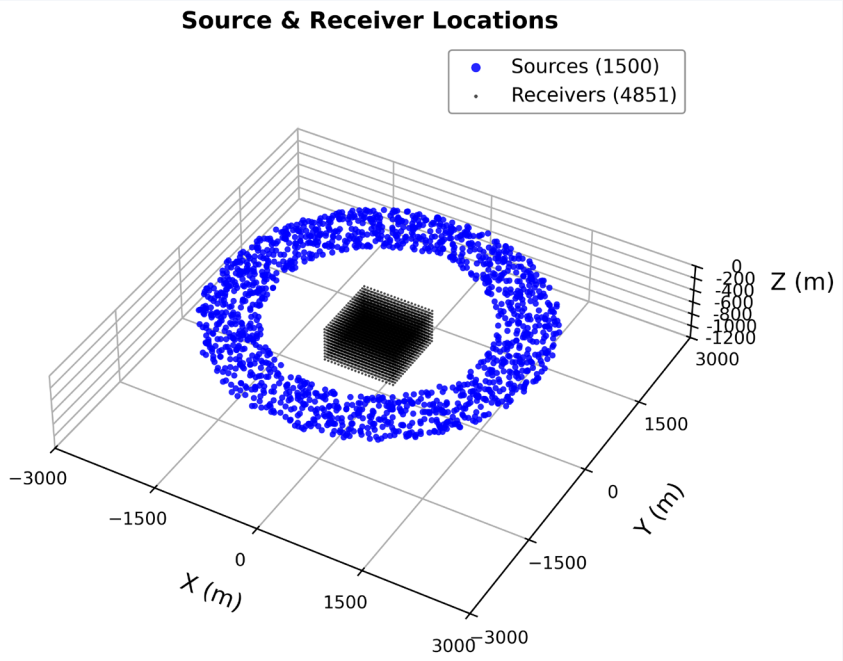
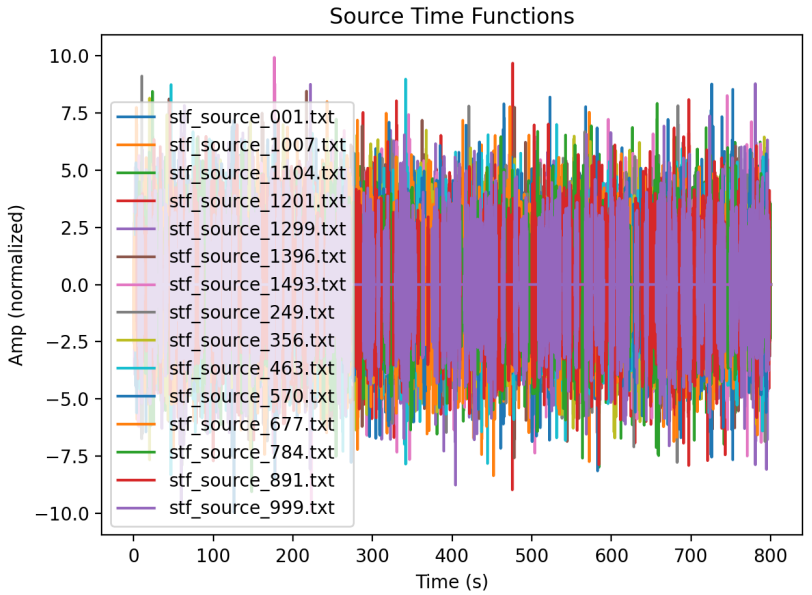
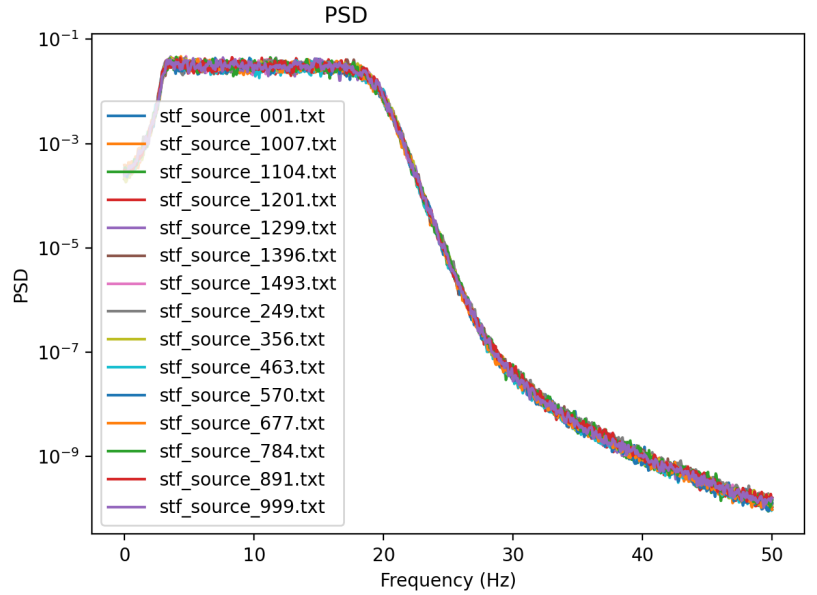
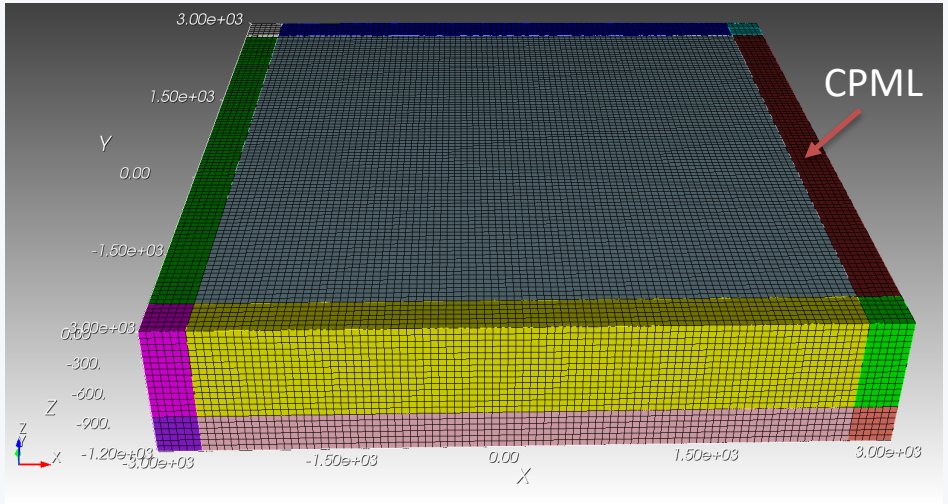
Random Sources Simulation: Model Setup





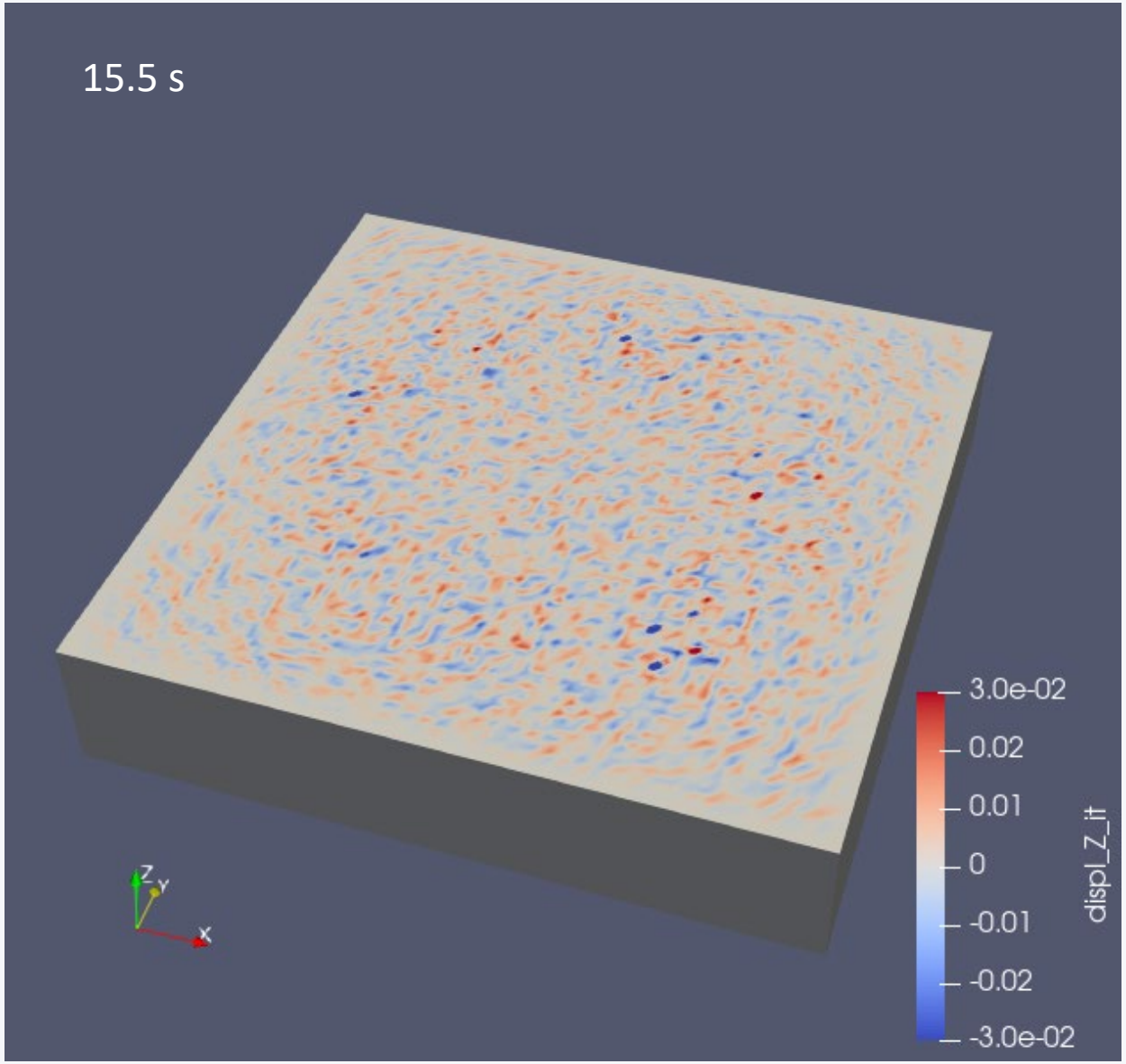


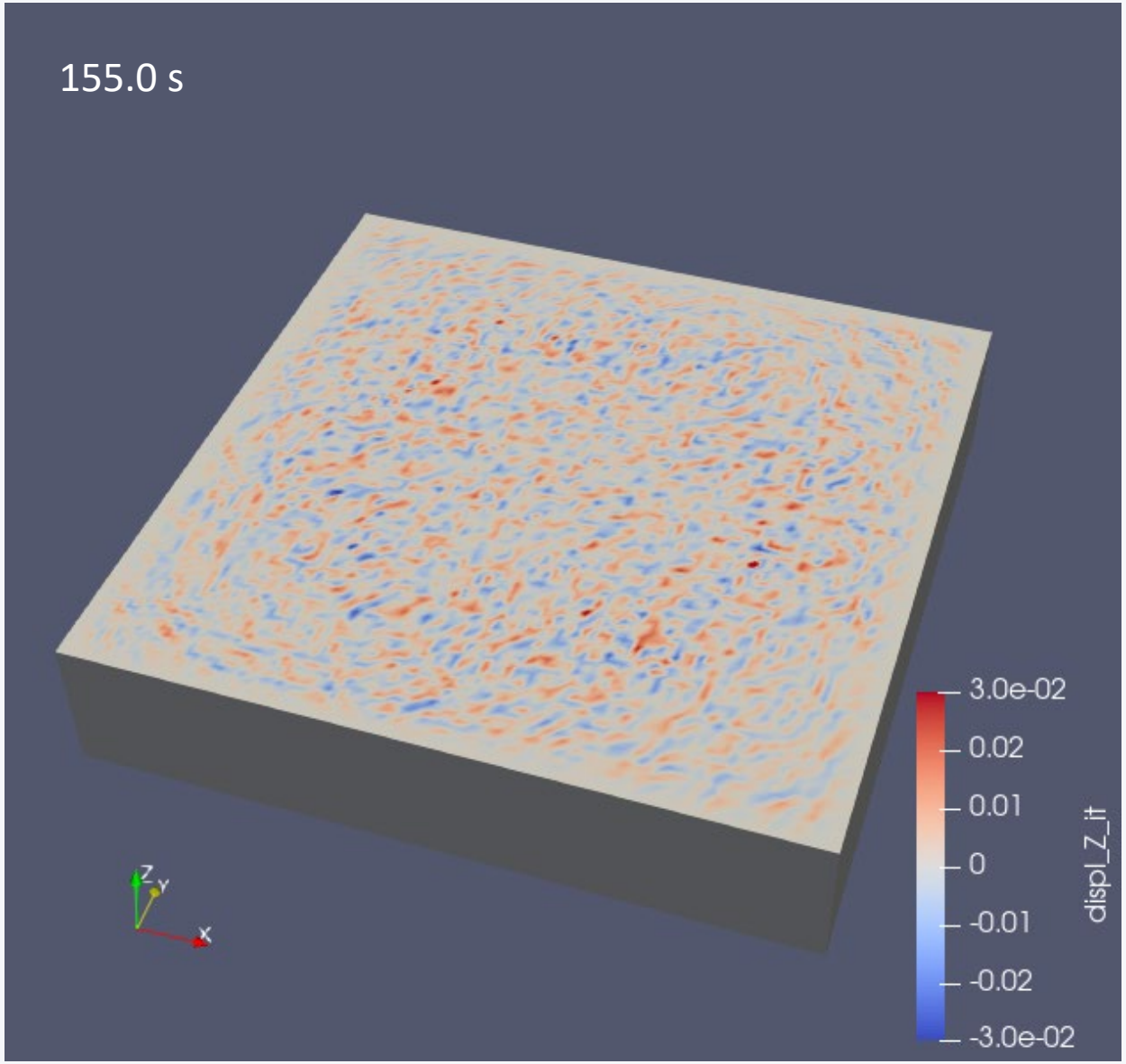


- 1,500 sources are distributed on an annulus surrounding the receiver array;
- Sources are constrained to the surface;
- Each source is assigned an independent, uncorrelated STF with a white spectrum between 3–20 Hz.

Homogeneous model: $\rho = 2500\ kg/m^3, vp = 4200\ m/s,\ \ vs = 2500\ m/s.$

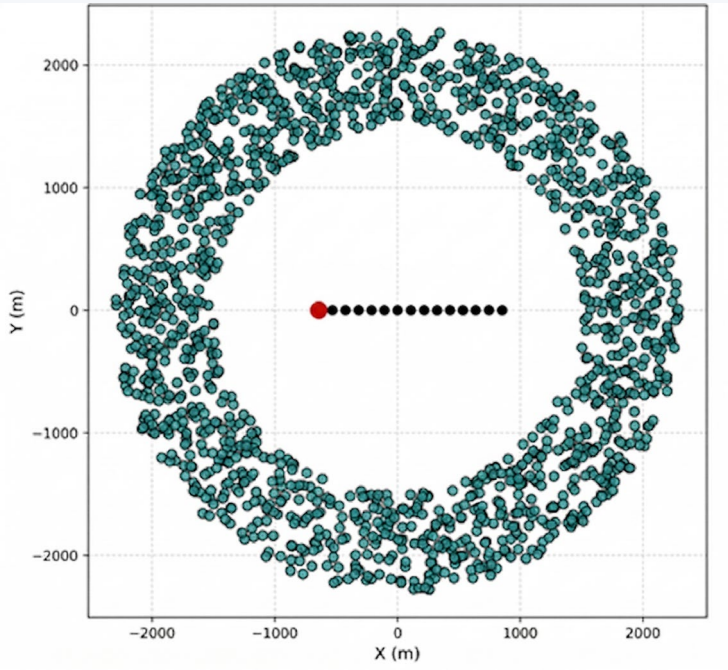
Random Sources Simulation: Snapshots





Random Sources Simulation: Cross Correlations

Record sections of cross correlations between the first and 20 other receivers in a linear array



Homogeneous model:
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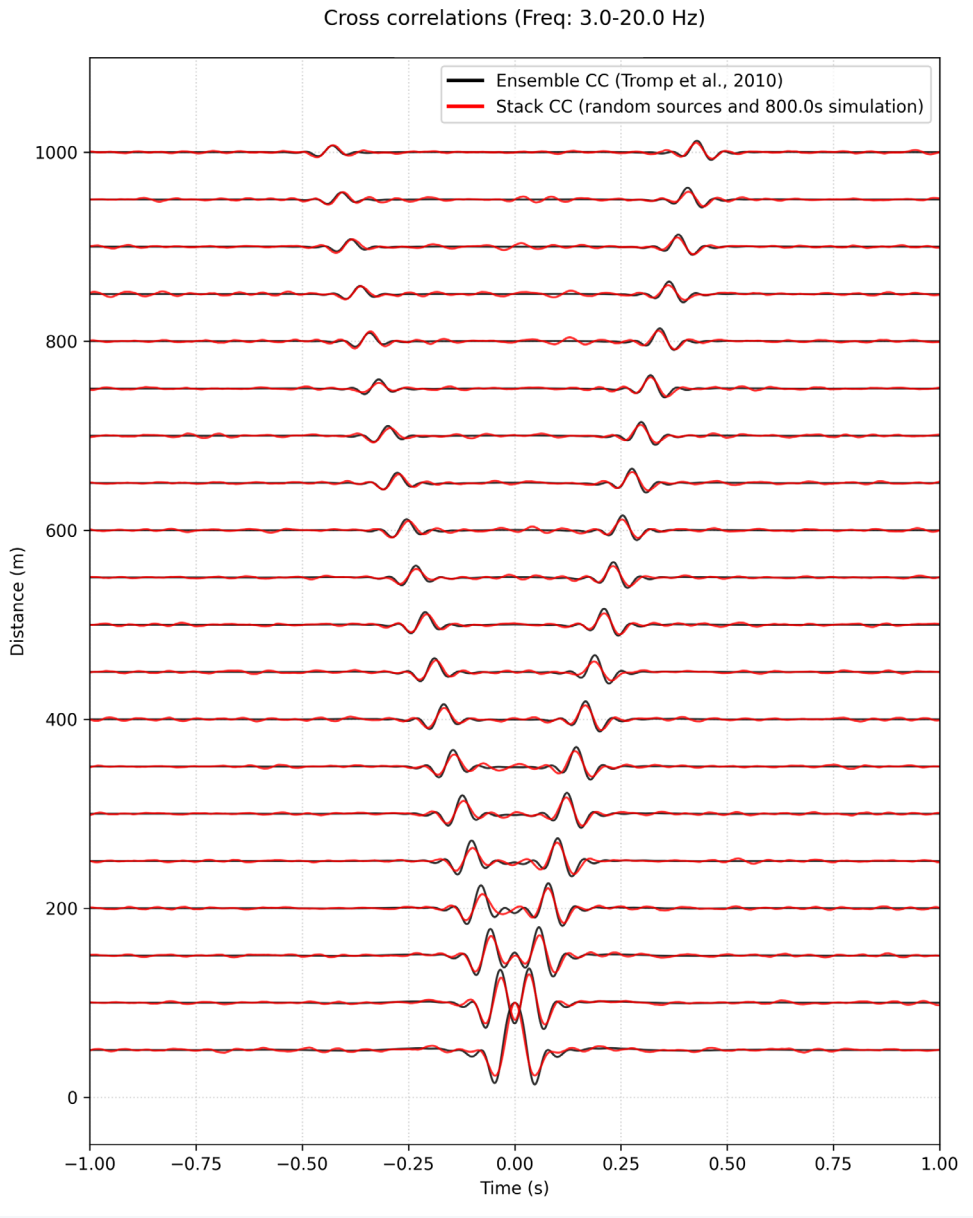
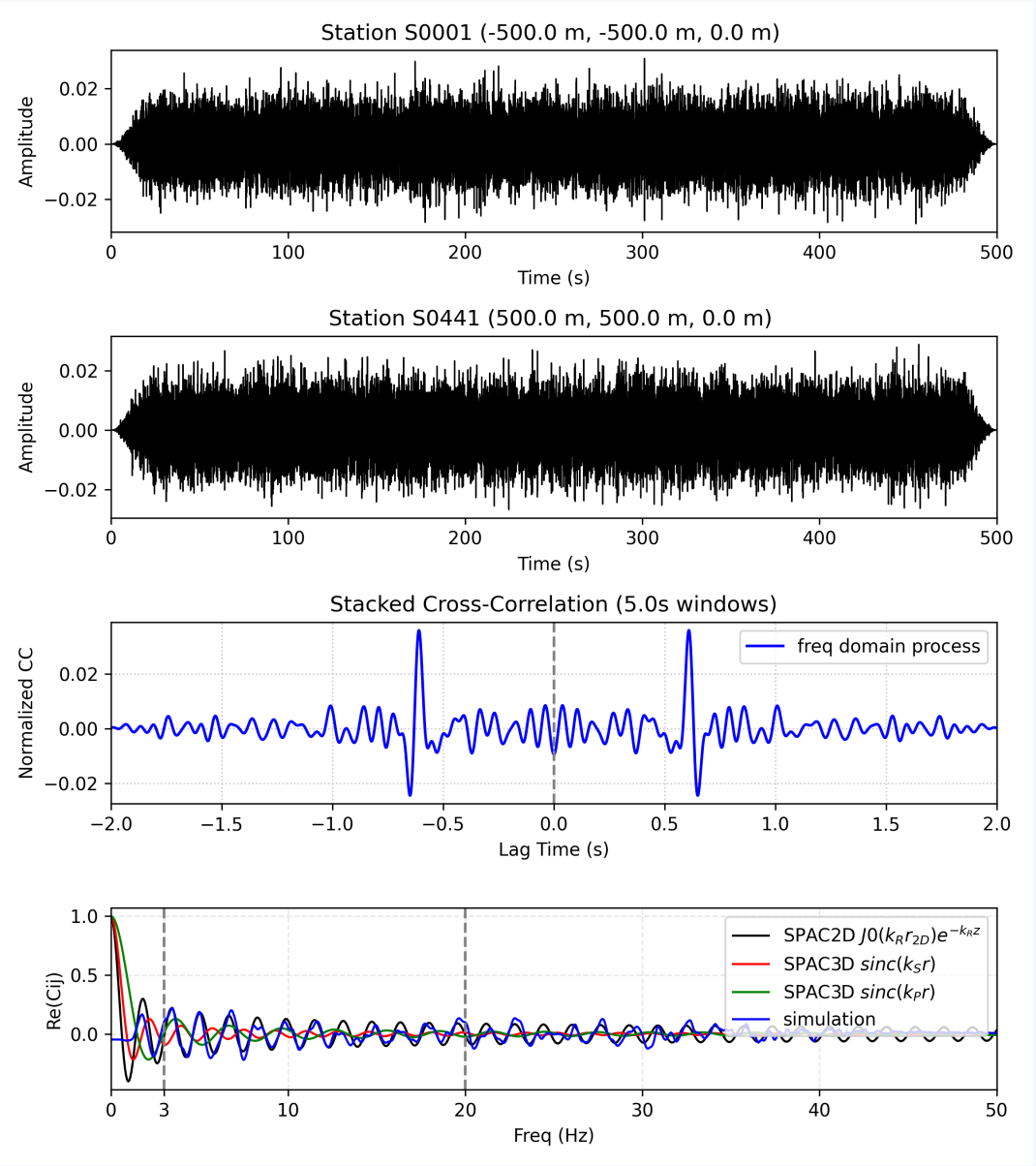
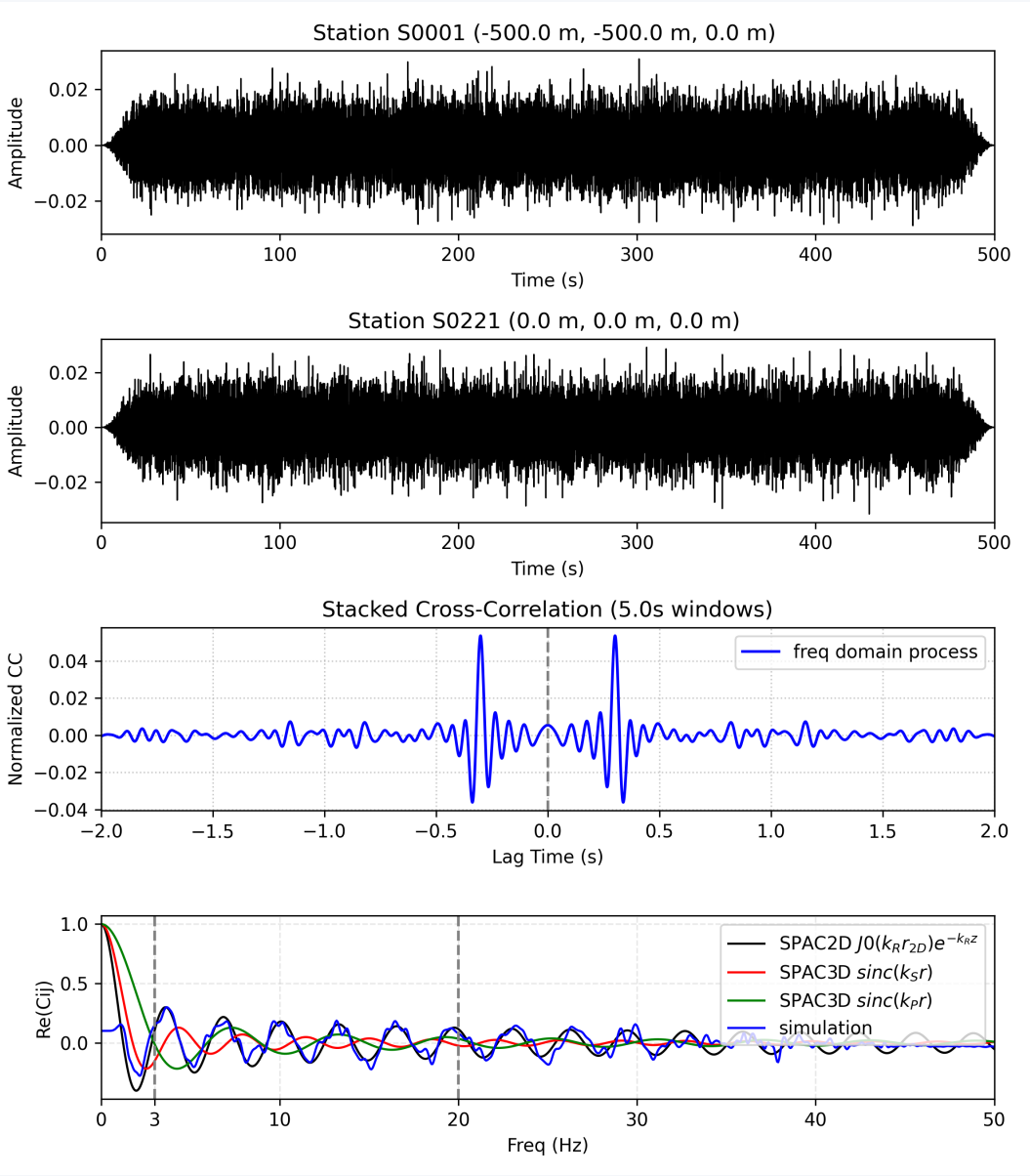
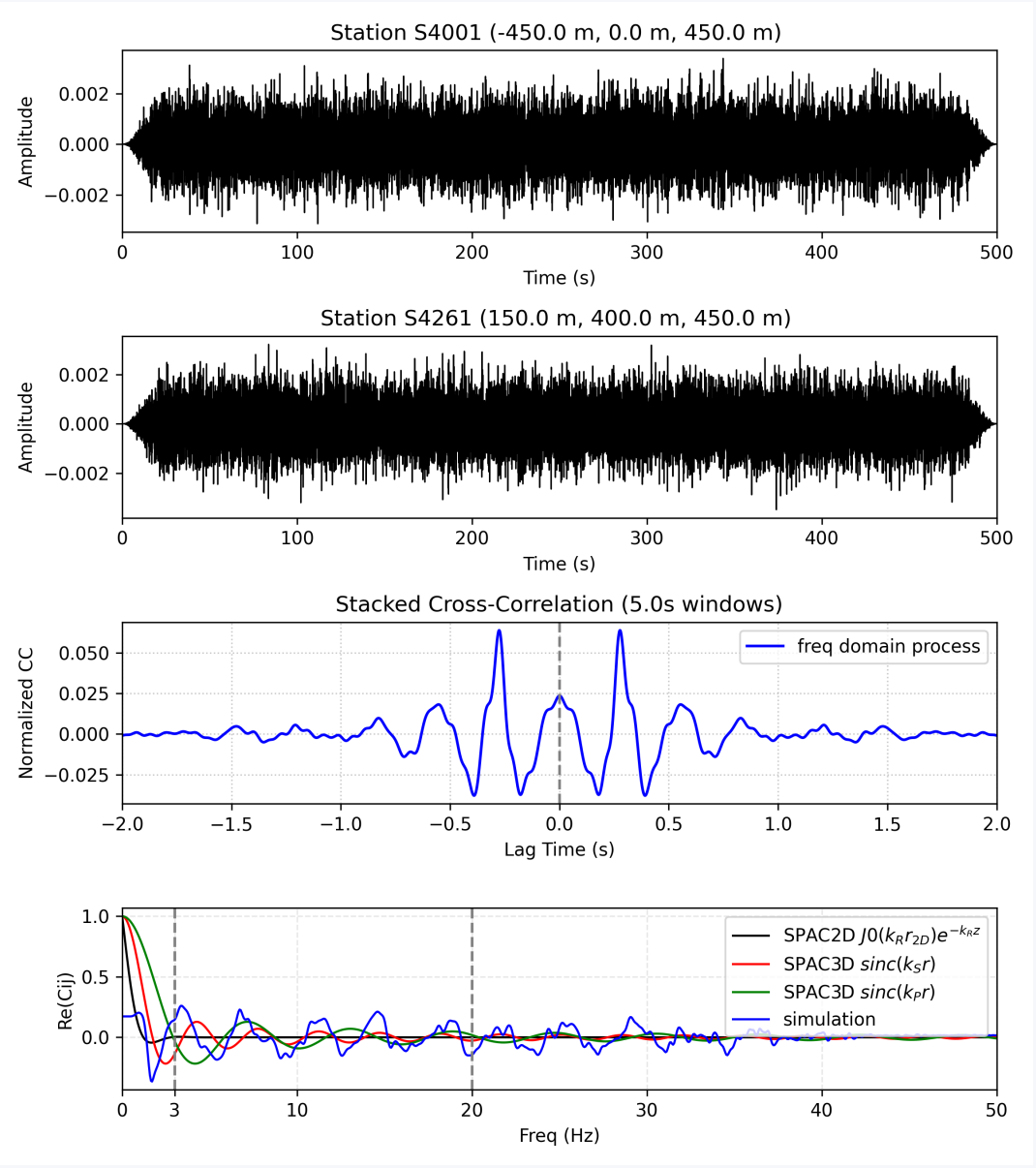


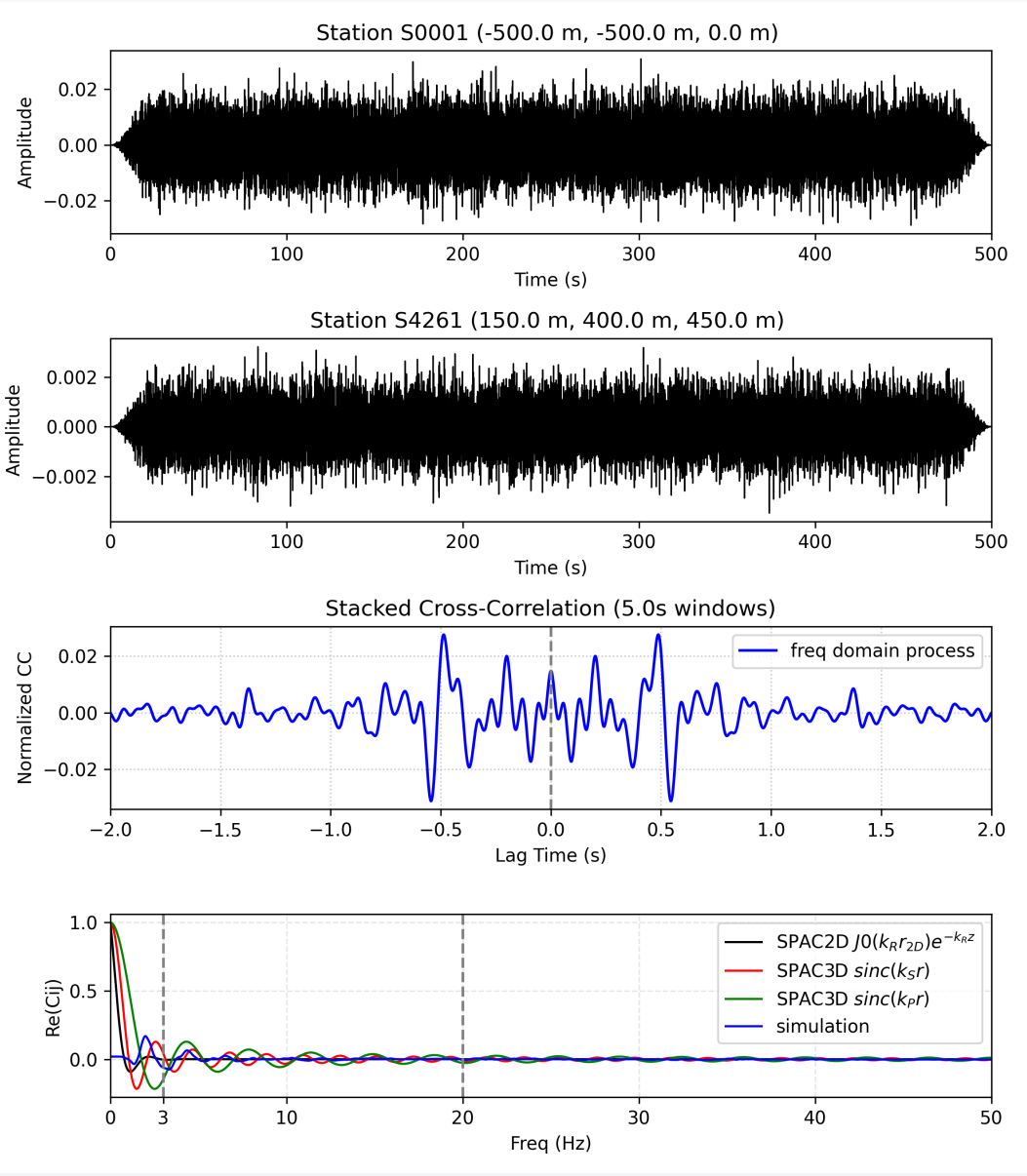
Simulated CPSDs compared against analytical predictions (SPAC) — surface records





Simulated CPSDs compared against analytical predictions (SPAC) — underground records





Computational Cost: Adjoint Method vs Random Source Simulation

Adjoint Method

- One independent simulation per main receiver
- Yields Green's function from that receiver to all points
- N receivers → N independent runs

Cost scales as O(N) × Lag Time × 2

For N more than 10^3, this becomes prohibitively expensive.

Random Source Simulation (This Work)

- Distribute random sources on an annulus at the free surface
- Run one long SEM simulation
- Record wavefields simultaneously at all receiver positions
- Extract CC / CPSD from the long time series
- All N receivers processed in a single run

Cost: O(1) × T_SEM (one long-duration simulation)

All receiver-pair CPSDs recovered from a single run.

Although the single simulation must be sufficiently long for CC convergence, the total cost remains significantly lower for large N.

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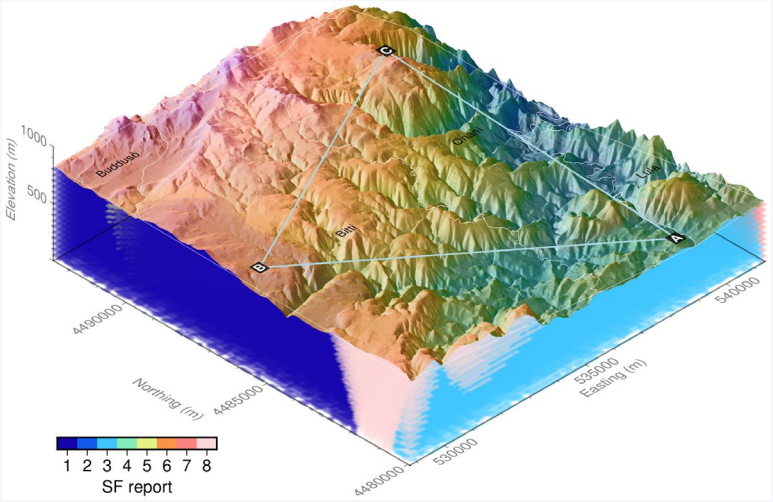
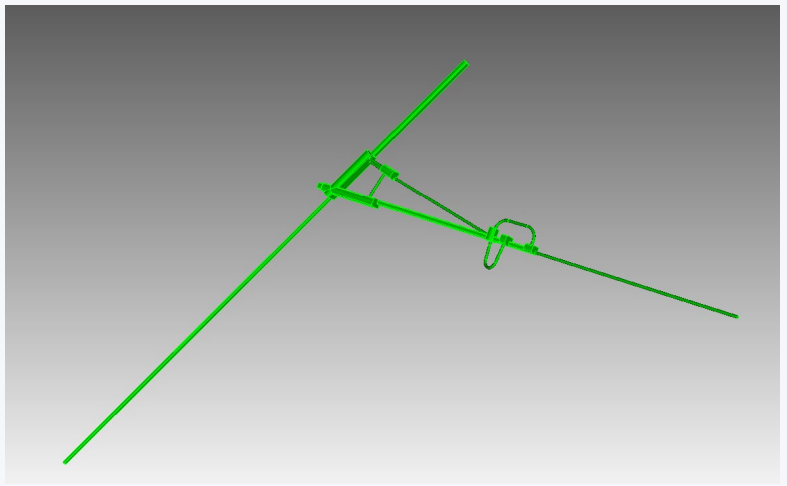
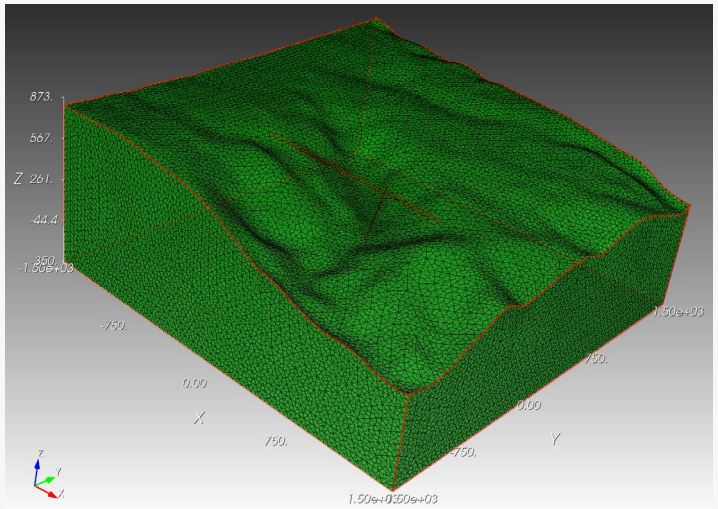
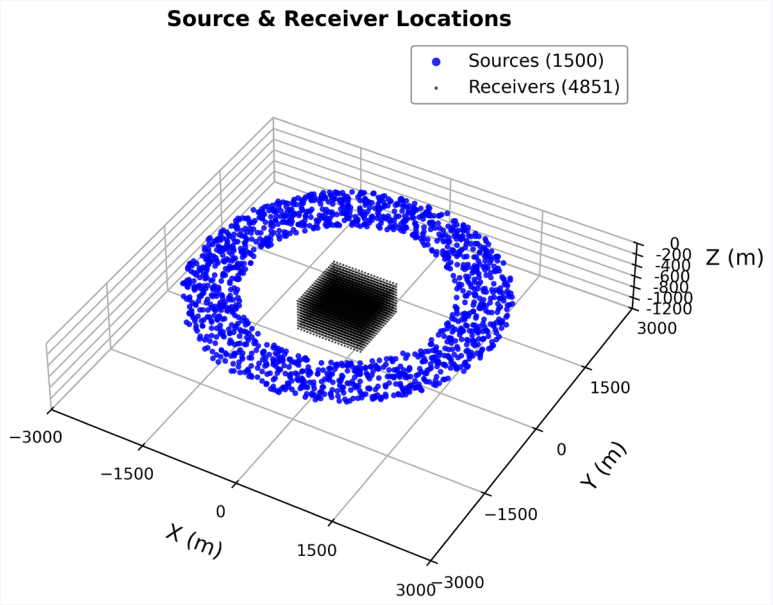
Summary of Current Progress





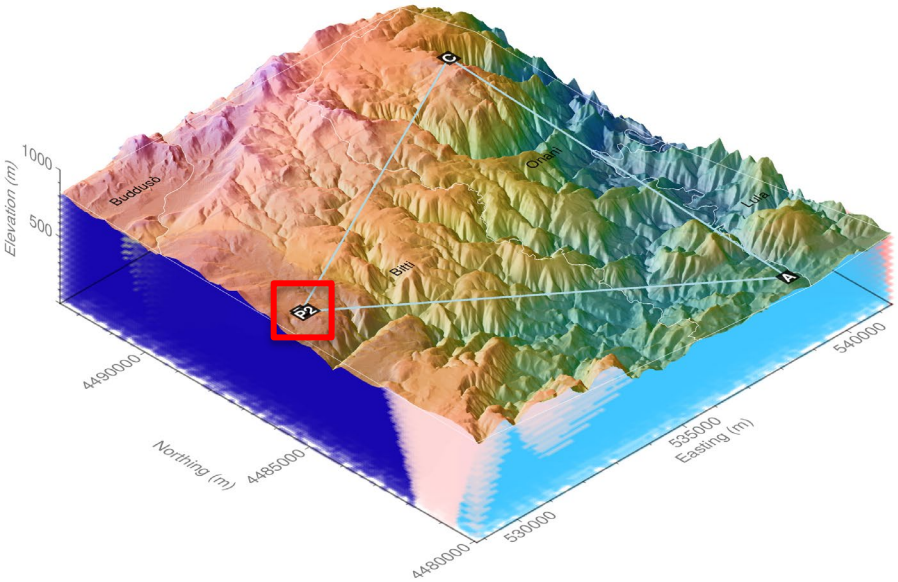


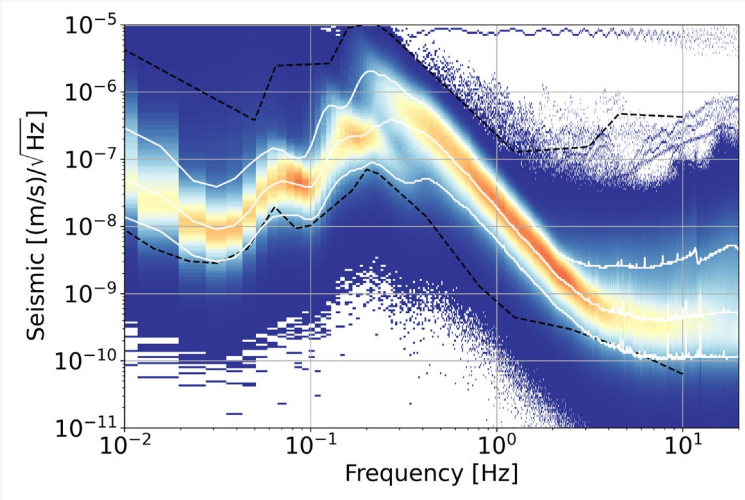


- SEM model with simplified cavern, topography, and geological structure.
- Random sources simulation method.

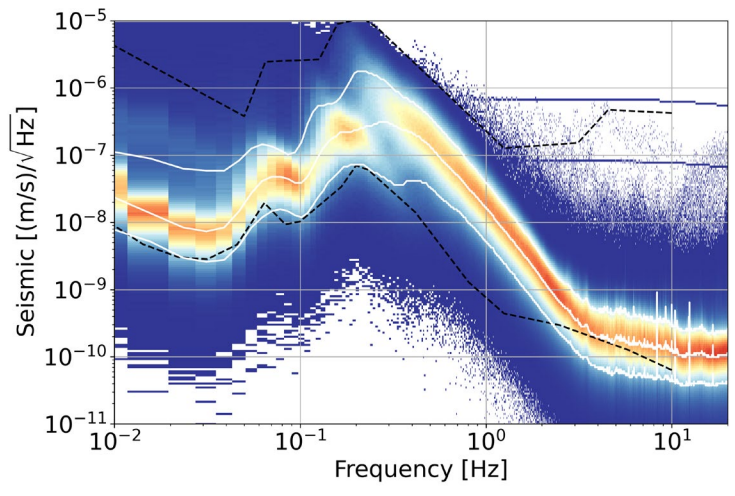
Future Work

Part I: Spectral Calibration with Site Measurements





Surface (P2)



Borehole (P2)

Part II: Deliver an SNN modeling pipeline and apply it to one ET vertex by July 2026

Thank You for Your Attention!

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