Numerical tools for multiscale wave propagation in geophysics

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Context

Current methods of elastic tomography in geophysical media are mainly based on the arrival times of the first waves, which correspond to a particular homogenization regime. The late coda, that corresponds to a diffusion-like regime, and cannot be processed with classical deterministic approaches, is mostly disregarded. Our long-run objective is to complement the classical tomography methods with statistical information gathered from the coda and the higher frequency content of the recorded signals. Such an objective requires the construction of numerical tools that can efficiently adapt to the required scale of study, in particular (i) a scalable mesh device that automatically considers topographical details up to a parametrizable level (ii) a spectral element solver for elastic wave propagation, and (iii) a scalable random field generator for elastic parameters.

Upscaling wave propagation

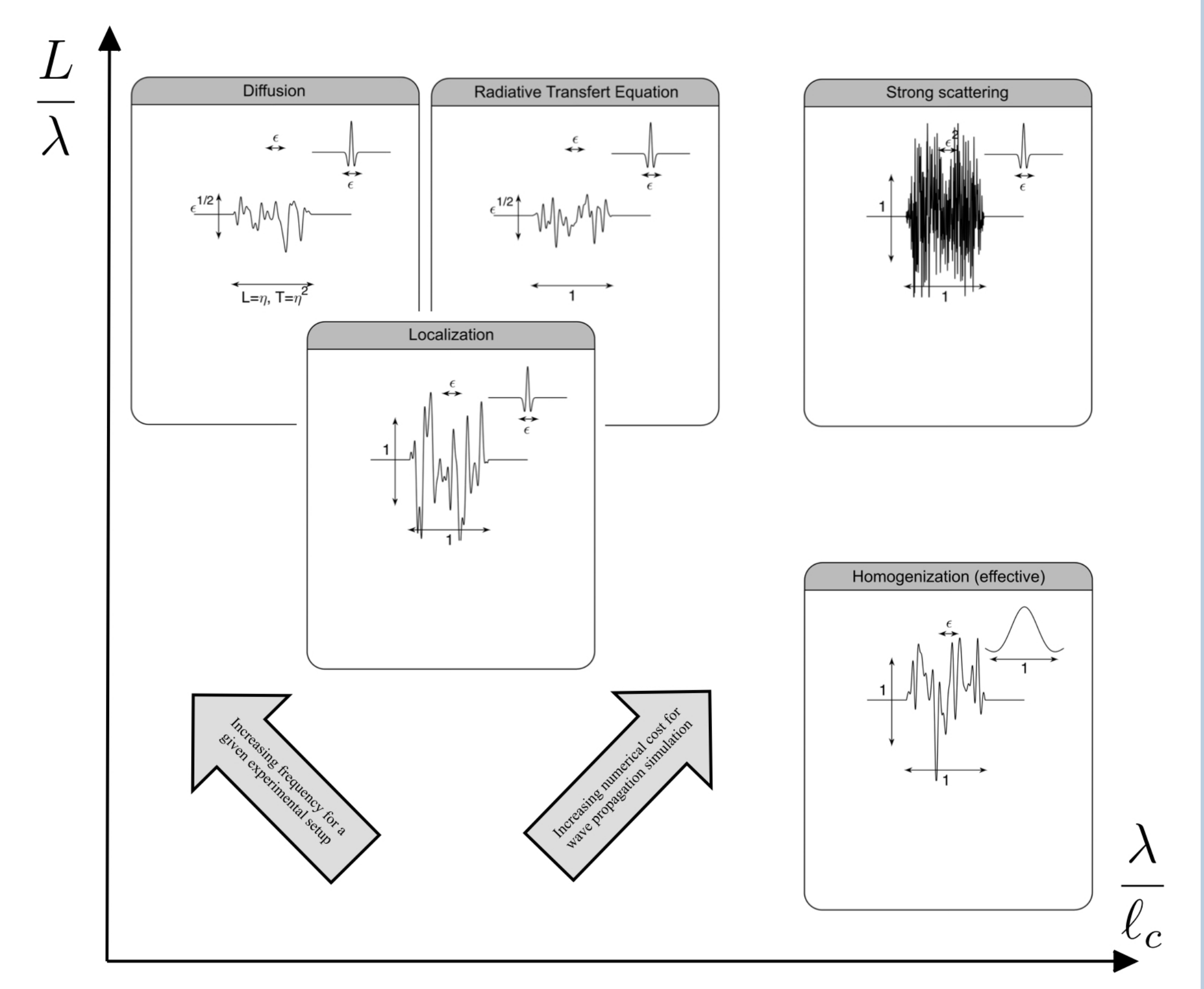

Figure 1: Different upscaling regimes for different ratios of the wave length λ, correlation length ℓ_c and propagation length L.

Wave propagation

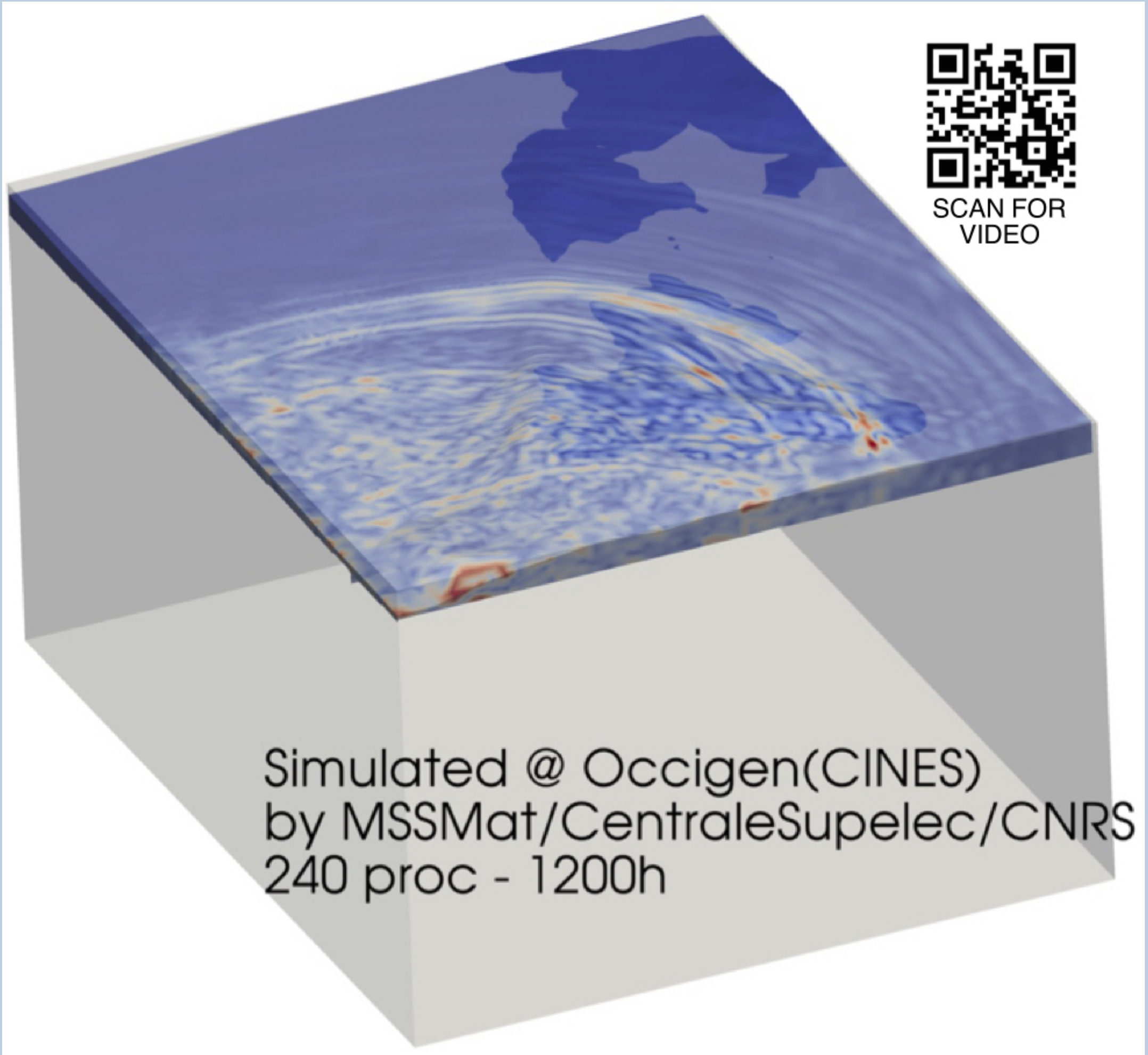

Figure 2: Snapshot of the wave propagation in a large Argostoli heterogeneous model (mechanical properties are random fields with log-normal density, Gaussian correlation, average values $V_p = 6500$ m/s, $V_s = 3800$ m/s, and $\rho = 1900$ kg/m^3, 10% correlation coefficient, and $\ell_c = 1000$ m).

Acknowledgements

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References

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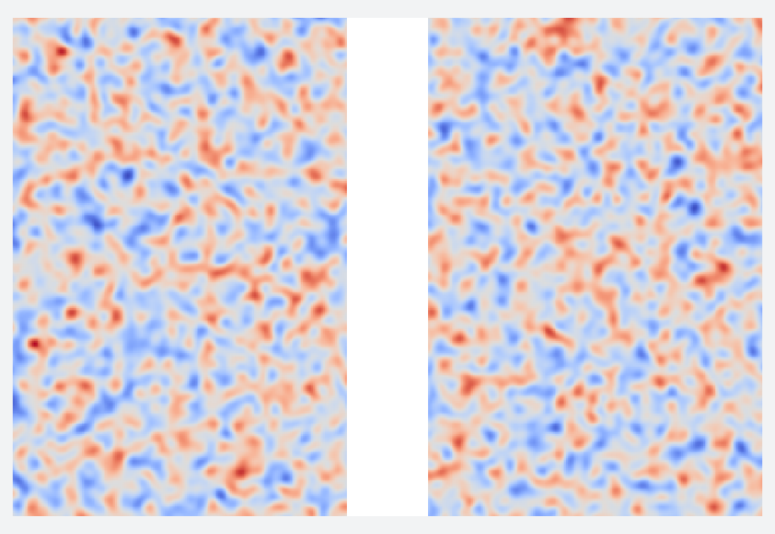
[2] R. Schneiders and R. Bünten. Computer Aided Geometric Design, 12(7):693 – 707, 1995. Grid Generation, Finite Elements, and Geometric Design.
[3] R. Schneiders, R. Schindler, and F. Weiler. In Proceedings of 5th International Meshing Roundtable, pages 205–216, Pittsburgh, PA, USA, 1996.
[4] J. Camata and A. Coutinho. Concurrency and Computation: Practice and Experience, 00:1–17, 2012.
[5] http://www.ngdc.noaa.gov/mgg/global/global.html

Scalable random field generator

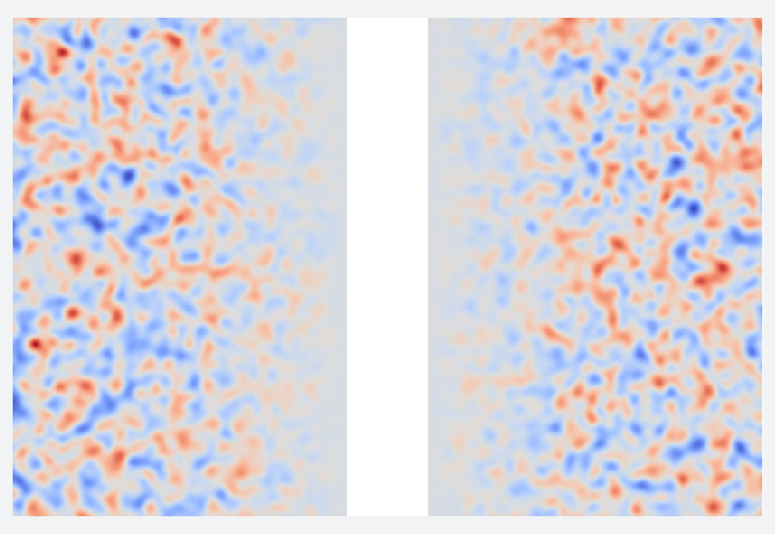
We therefore propose to generate a realization over the entire domain as a superposition of smaller independent realizations, gluing them together through transition volumes. The number of operations per processor then remains constant, even when $L \gg \ell_c$. Results and theory have shown that a transition volume of 5 to 10 ℓ_c is enough to make statistics homogeneous over the whole domain.

Random Field Generation Procedure (case $\ell_c \ll L$)

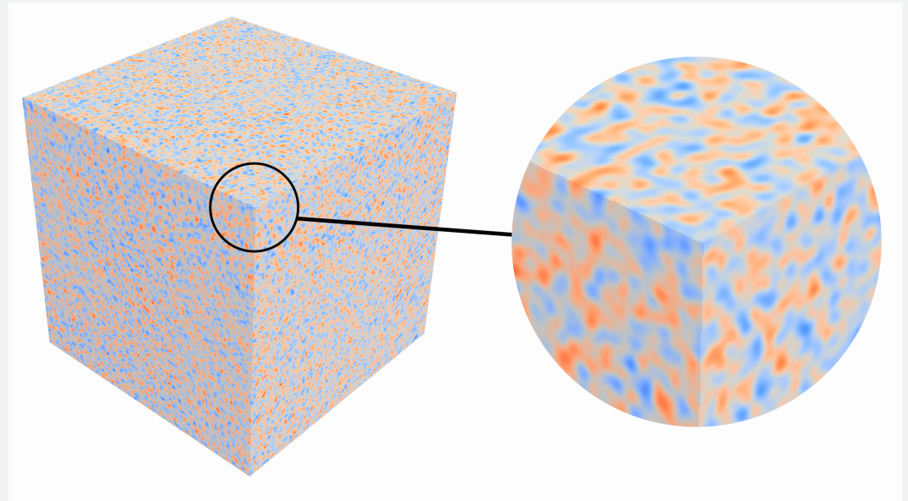
Step 1: Independent generation on each proc.



Step 2: Weighting functions on the overlap



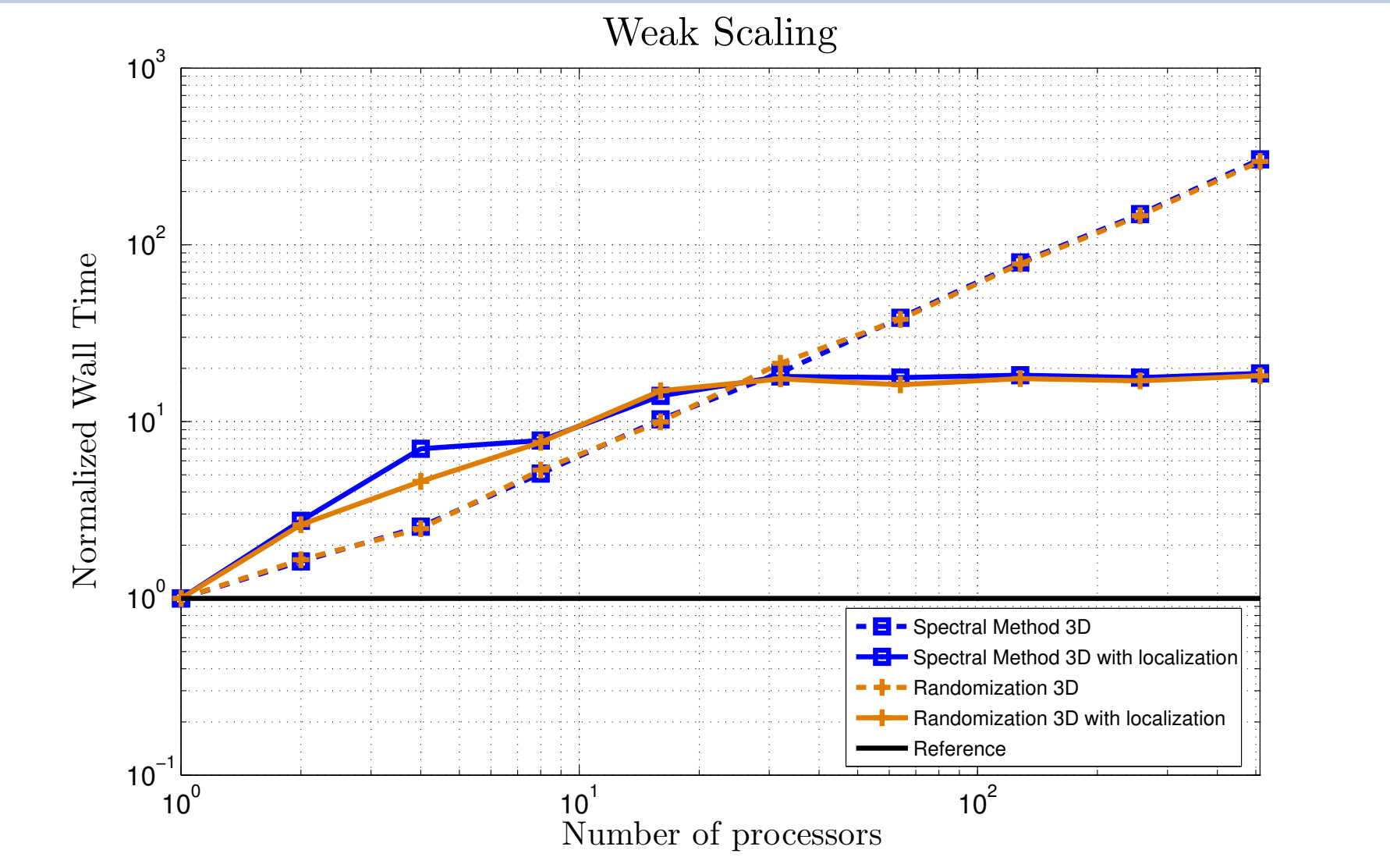
Step 3: Merging on the overlaps



Weak scalability analysis

Cores	Nodes	Generation Time (s)	
		Standard	Localized
16	4×10^6	227	320
128	32×10^6	1778	375
512	13×10^7	6761	388

Machine: Altix ICE 8400 LX (2.66GHZ) / ∼ 816 cores



Scalable hexahedral mesh generator for geophysics

- Meshing is particularly hard considering high-resolution wave propagation problems using conformal hexahedra in realistic Earth geometries [1,2,3].
- We extend the parallel octree-mesh generator [4] to 3D unstructured conformal hexahedral meshes based on 3-octree with a custom 13-cell template for vertical transitions.
- 3-Octree: data structure where a cell is divided into 27 new cells, recursively. At level l, a 3-octree has up to 3^{3l} cells.

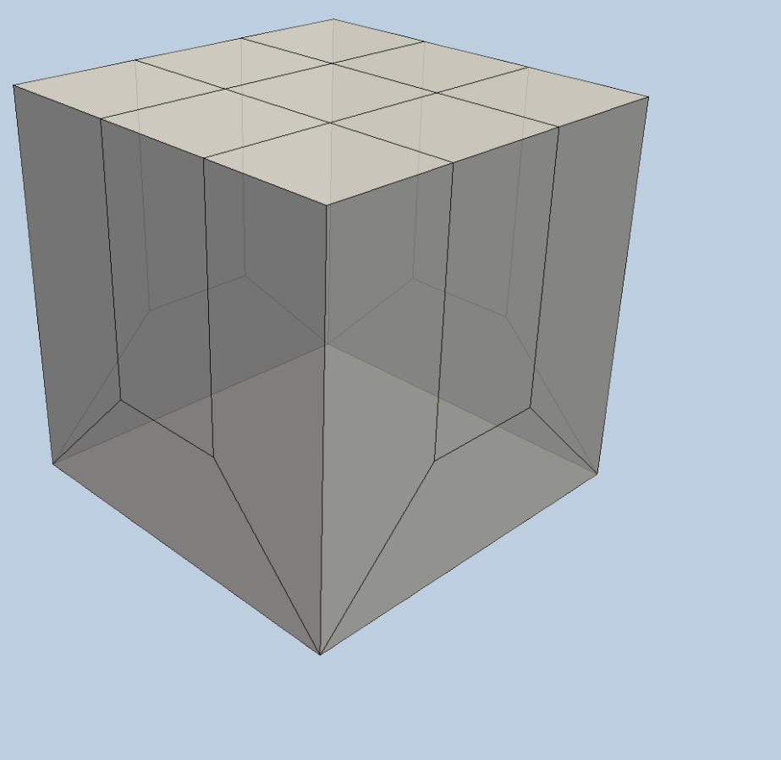


Figure 3: 13-cell template used to remove face hanging nodes

Meshing Procedure (for chosen maximum octree level l):

Step 1: Get bathymetry

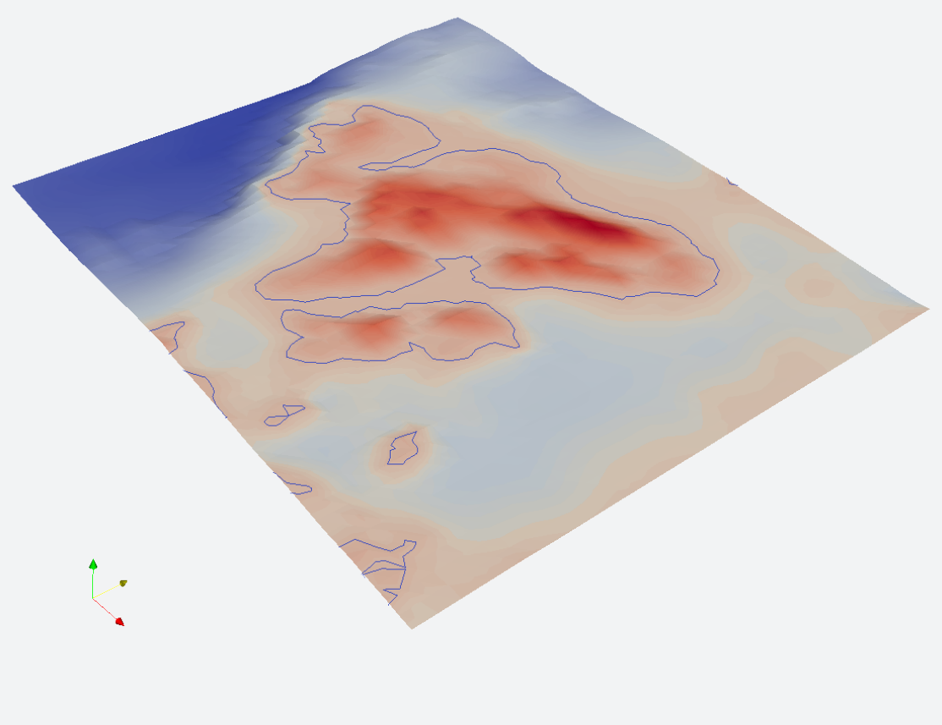


Figure 4: STL surface generated from NOAA bathymetry dataset [5] for Argostoli site

Step 2: Octree bottom-up construction

(i) 3-Octree Initialization
  Parallel 2D decomposition
(ii) From upper layers:
  Insert cells at level l
  Each m meters, insert a transitional cell layer and $l = l - 1$
(ii) Generate Mesh:
  Get hexahedral connectivity
  Build communication map

Step 3: Boundary Fitting

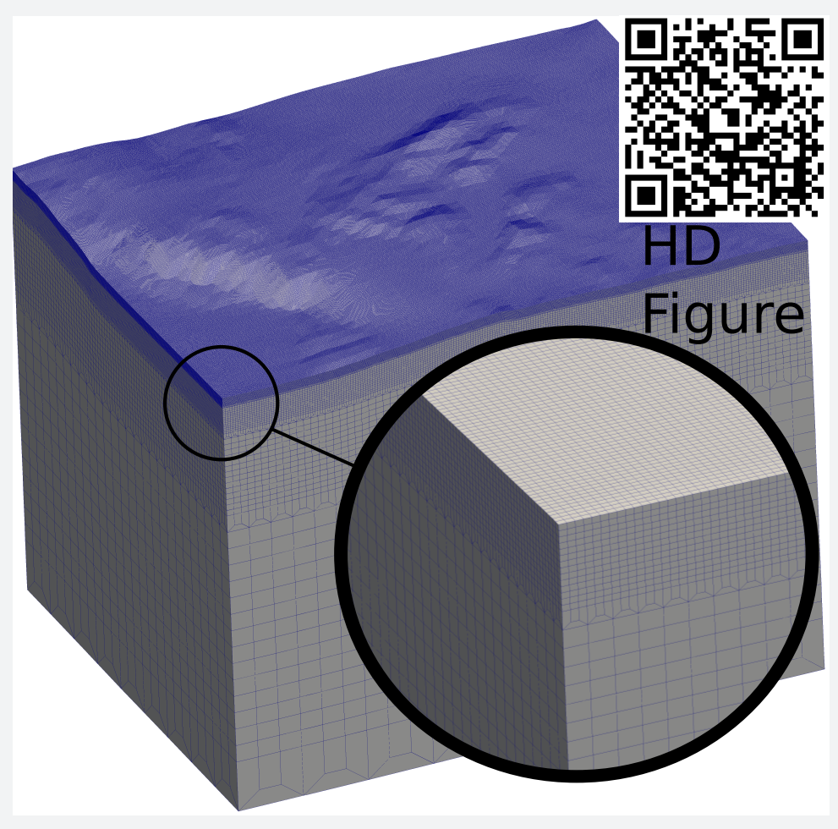


Figure 5: Coarsest Mesh for Argostoli (generated @Occigen)

Weak scalability analysis

Cores	levels	Nodes	Elements	Time (s)	Comm(%)
3^4	7	85,602,744	83,102,679	12.061	21 %
3^5	8	769,790,232	747,937,476	32.994	20 %
3^6	9	6,926,153,724	6,731,438,013	105.188	25 %
3^8	10	62,330,385,168	60,583,119,264	123.066	29 %

Tests carried out on Occigen machine: BULL,XEON E5-2690V3 12C 2.6GHZ / ∼50K cores