2024 CRESCENT Seed Grant Award Report

Multi-Resolution and -Scale Synthesis of Cascadia Earth Models

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Did you accomplish what you set out with this project?

Yes. The overarching goal of the project was to develop an accessible framework for constructing multiscale and multiresolution Earth models for Cascadia using existing publicly available models. Here, we have completed the development of a prototype software, GridQuery (GQ)(Ajala et al., 2025), which is more flexible, accessible, and general than existing model synthesis programs like the SCEC Unified Community Velocity Model (UCVM) Software (Ajala, 2021; Small et al., 2017). GQ is developed using the GMT API (Wessel et al., 2019) and, thus, benefits from many functions that facilitate grid manipulation. Using the window function technique of Ajala and Persaud (2021), we have developed modules that allow for merging multidimensional NetCDF grid files describing any model parameter (e.g., Fig. 1). As a result, our application extends beyond simply merging seismic wave speeds and can be applied to other important model parameters of the Earth (Fig. 2), like topography, potential fields (e.g., gravity or magnetic), geodetic fields, resistivity, porosity, temperature, viscosity, etc., defined from the surface of the Earth to the core, that are essential for understanding the structure, composition, and evolution of our planet and for informing natural hazard assessment. Since the approach does not rely on optimization techniques, machine learning, or diffusion-based partial differential equations (PDEs), it is computationally tractable for complex merging tasks. Due to the advantages of the GMT API's functionality in processing grids row by row, synthesizing the globe at a fine grid spacing is trivial. Furthermore, the popularity of GMT in the scientific community and its ecosystem of friendlier computing environments, such as MATLAB (GMTMEX), Python (PyGMT), and Julia (GMT.jl), which offer interfaces to GMT modules, may promote the adoption of GQ once it is released to the public. A simple example on the West Coast of the U.S. illustrates the synthesis of multiscale and multiresolution shear wave speed models in California and Cascadia, demonstrating the application of the merge2d module contained in GQ (Fig. 3). The development of GQ is timely. As new technologies and techniques in seismology, like the application of machine learning, nodal or dense seismic arrays, and fiber optic sensing, allow for the development of more detailed Earth models, the results will need to be incorporated into existing lower-resolution models to enhance structural and source studies, including Earth model inversion, development of high-resolution earthquake catalogs, physics-based ground motion modeling, dynamic earthquake rupture modeling, and earthquake and tsunami hazard assessments.

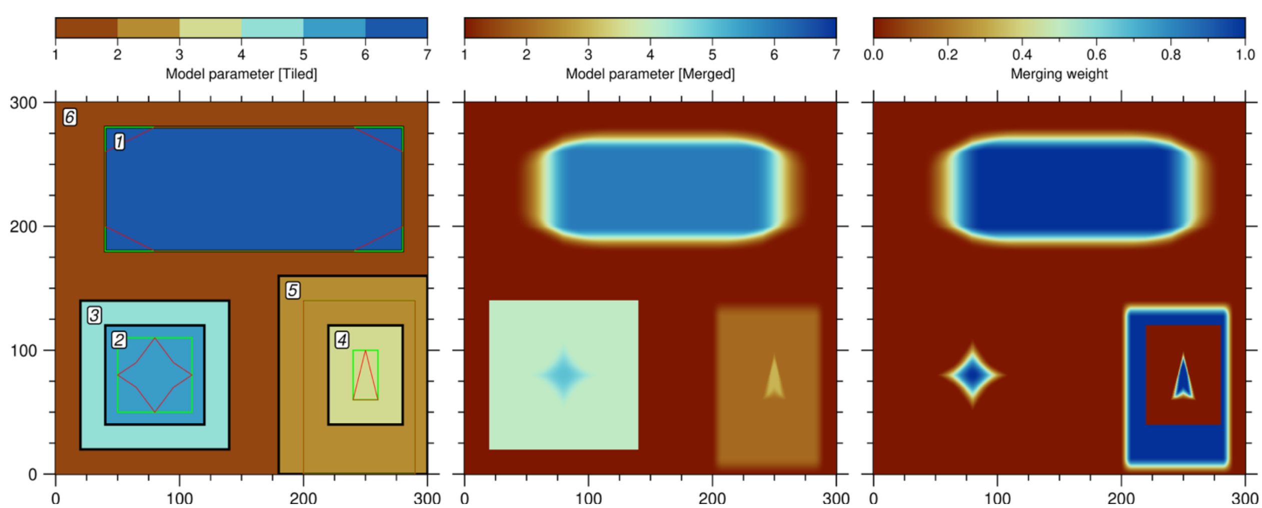


***Fig. 1| Merging concept illustrated with merge2d*.** **left,** Six models tiled according to the labeled number. The black polygon represents the outer extent of the model. The red polygon represents a subregion of the model to be merged with another model. The green polygon is the bounding box of the red polygon. NOTE: all the polygons for each model can coincide. **center,** Hybrid merged model developed by combining the models through local pairing and blending. Within the inner region, a window function is used to merge the model with a selected pair, preferably chosen as the model on the immediate exterior. Outside of the inner region, the other model pair is returned. **right,** Merging weights used to synthesize the hybrid model. In this example, 1 is paired with 6, 2 is paired with 3, 3 is unpaired, 4 is paired with 5, and 5 is paired with 6. It is, thus, possible to make many nested embeddings. With GMT, memory is not a limiting factor because grid operations are executed row by row (i.e., global grids at fine grid spacings are computationally tractable).

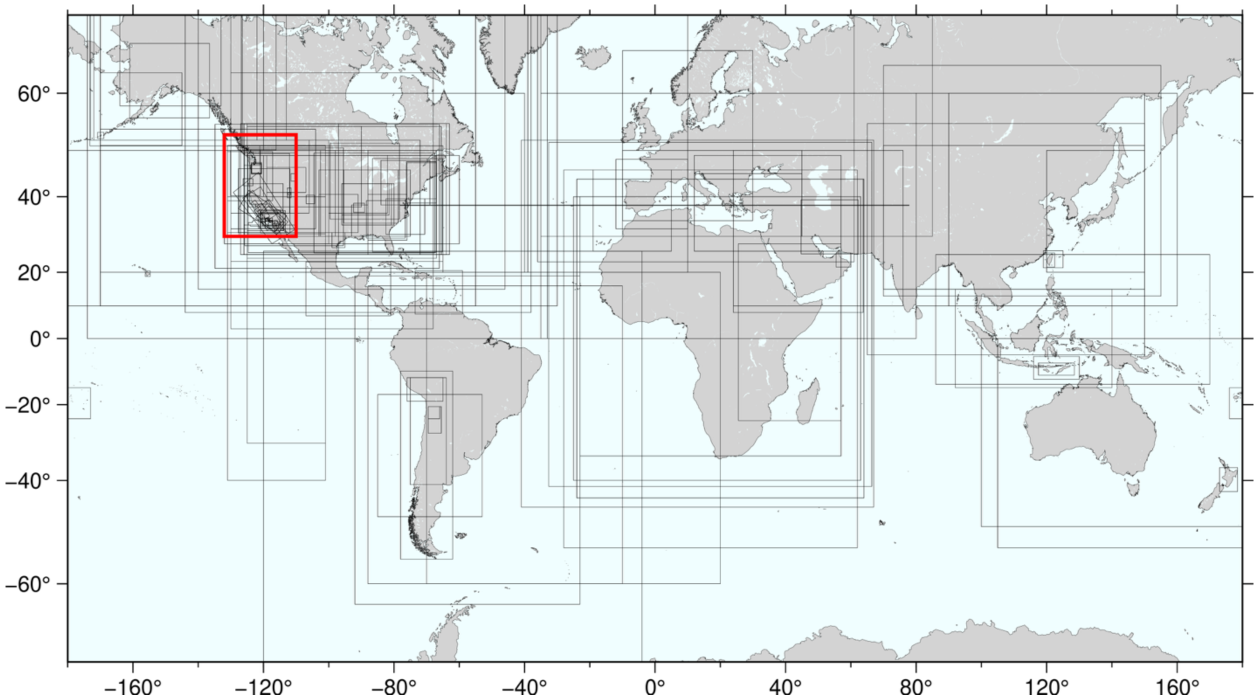


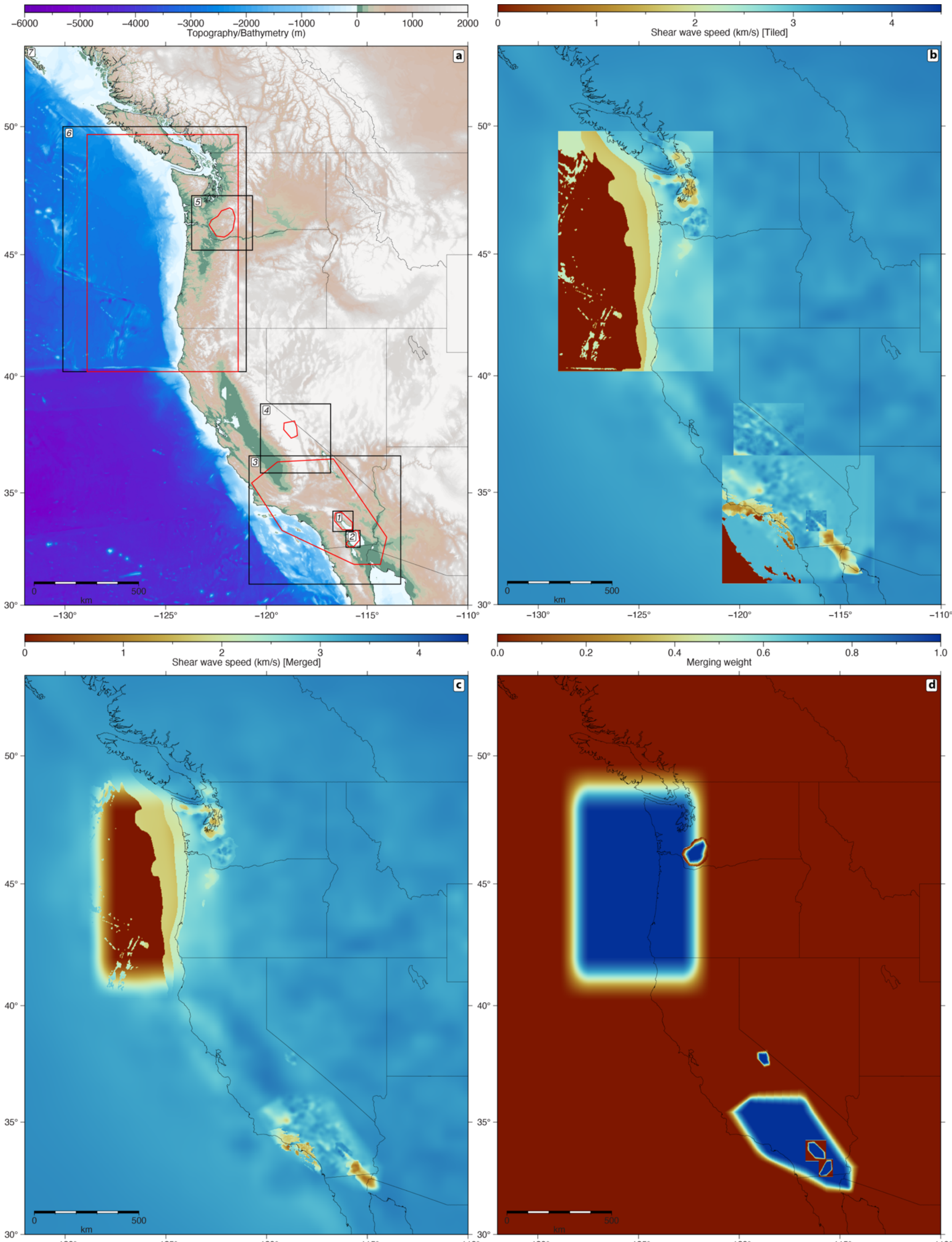
***Fig. 2| Coverage of a subset of publicly available Earth models*.** A compilation of the extent (black rectangles) of publicly hosted Earth models from the Earthscope EMC (Hutko et al., 2017), CRESCENT CVM model viewer (Bahavar et al., 2025), and SCEC UCVM software (Small et al., 2017). These models are multiscale, multiresolution, multidimensional, and include different model parameter types (e.g., temperature, wave speeds, resistivity, density, interfaces, etc.).

What is the next step for development of this project/priority?

The project greatly benefitted from discussions with the CRESCENT CVM Working Group. Thus, the work shall continue to evolve in collaboration with activities in the CRESCENT CVM Team. The top priority is to release the first version of GQ, which will allow users to merge multiple multiscale and multiresolution 2D and 3D NetCDF grid files. The plan is to have GQ released over the coming summer and to have manuscripts that describe the core idea and the software package. Once the CRESCENT CVM model version 0 is developed, we will utilize it to synthesize a suite of multiscale Earth models for Cascadia that embeds detailed local models for ground motion validation studies. There are also plans to implement the model synthesis algorithm in the CRESCENT CVM model viewer (Bahavar et al., 2025), providing an even easier avenue for the community to develop multiscale models in Cascadia for various applications.

Where did you publish/present on this work?

Two manuscripts related to the work are in preparation and will be submitted to high-impact journals over the summer. We presented progress on the research at the recent Seismological Society of America 2025 Annual Meeting in Baltimore, MD (Ajala et al., 2025 - publicly accessible on Research Gate).



Topography/Bathymetry (m)
−6000
−5000
−4000
−3000
−2000
−1000
0
1000
2000
Shear wave speed (km/s) [Tiled]
Shear wave speed (km/s) [Merged]
Merging weight
0.0
0.2
0.4
0.6
0.8
1.0
a
b
c
d
1
2
3
4
5
6
7
0
500
km
50°
45°
40°
35°
30°
−130°
−125°
−120°
−115°
−110°

***Fig. 3| Merging example of multiscale and multiresolution seismic wave speed models in the western U.S – California and Cascadia*.** **a,** Seven Earth models tiled according to the labeled number. 1 – Ajala et al. (2019) [Coachella Valley basin model]; 2 – Persaud et al. (2016) [Imperial Valley basin model]; 3 – Shaw et al. (2015) [SCEC CVMH regional model]; 4 – Biondi et al. (2023)[3D DAS model over the Long Valley caldera]; 5 – Ulberg et al. (2020) [Mount St. Helens local tomography]; 6 – Stephenson et al. (2017) [Pacific Northwest CVM V1.6]; 7 – Noe et al. (2024) [Global Earth model]. The black polygon represents the outer extent of the model. The red polygon represents a subregion of the model to be merged with another model. Here, the red polygons have a concrete definition as resolution boundaries (e.g., where the model parameters are well-constrained in a tomographic imaging problem). **b,** Tiled model showing shear wave speeds at 2 km depth. **c,** Hybrid merged model of the shear wave speeds at 2 km depth. **d,** Window function weights used in merging.

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