2023 SCEC Annual Report

Machine Learning-Based Tomography of Ridgecrest Region Near-surface S-wave Velocities

Scec award number: 23191

Science Objectives:

P3.d, P3.e, P3.a

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Proposal Review **Seismology**

Publication:

Zheng Zhou, Peter Gerstoft, and Kim Olsen, 3D Multiresolution Velocity Model Fusion With Probability Graphical Models, Bull Seismological Society Am., In press,

Zheng Zhou, Peter Gerstoft, and Kim Olsen, Graph-learning Approach to Combine Multiresolution Seismic Velocity Models, J Geophys Research, submitted 15 Aug

Intellectual Merit/abstract

Inspired by the progress in image editing and medical tomography fusion (James et al., 2014), we introduce a seismic tomography model fusion technique, which enhances the local detail structures and simultaneously preserves global smoothness in the combined model. Combining the physics-informed mechanism and the Markov random field model, we propose a probability graphical model (PGM) which captures the relation between subdomains with multiple resolutions, in terms of high-resolution (HR) and low-resolution (LR). By transferring the information from the HR regions, the details in the LR areas are enhanced by solving a maximum likelihood problem with prior knowledge from the HR areas. Evaluation tests on both checkerboard and a real fault zone model derived from the 2019 Ridgecrest, CA, earthquake demonstrate its efficacy.

Broader Impacts

The work has supported one graduate student.

Report

The project is carried out by graduate student Zhen Zhou with Peter Gerstoft as lead-PI. Professor Kim B Olsen also participated in the project.

(1) We have developed a probability graphical model-based tomography combining method. The variability in spatial resolution of seismic velocity models obtained via tomographic methodologies is attributed to many factors, including inversion strategies, ray path coverage, and data integrity. Integration of such models, with distinct resolutions, is crucial during the refinement of community models, thereby enhancing the precision of ground motion simulations. Toward this goal, we introduce the Probability Graphical Model (PGM), combining velocity models with heterogeneous resolutions and non- uniform data point distributions.

(2) Generalize our proposed method to some real tomography model combining problems, and evaluate by preserving travel times along ray paths. The PGM integrates data relations across varying- resolution subdomains, enhancing detail within low-resolution domains by utilizing information and prior knowledge from high-resolution subdomains through a maximum posterior (MAP) problem. Assessment of efficacy, utilizing both 2D and 3D velocity models—consisting of synthetic checkerboard models and a fault zone model from Ridgecrest, CA—demonstrates noteworthy improvements in accuracy, compared to state-of-the-art fusion techniques. Specifically, we find reductions of 30% and 44% in computed travel-time residuals for 2D and 3D models, respectively, as compared to conventional smoothing techniques. Unlike conventional methods, the PGM's adaptive weight selection facilitates preserving and learning details from complex, non-uniform high-resolution models and applies the enhancements to the low-resolution background domain.

(3) The variability in spatial resolution of seismic velocity models obtained via tomographic methodologies is attributed to many factors, including inversion strategies, ray path coverage, and data integrity. Integration of such models, with distinct resolutions, is crucial during the refinement of community models, thereby enhancing the precision of ground motion simulations. Toward this goal, we introduce the Probability Graphical Model (PGM), combining velocity models with heterogeneous resolutions and nonuniform data point distributions. The PGM integrates data relations across varying-resolution subdomains, enhancing detail within low-resolution domains by utilizing information and prior

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(4) We have submitted two papers , a peer-reviewed conference (45 % acceptance rate) sand have presented the work at 3 conferences:

4a Zheng Zhou, Peter Gerstoft, and Kim Olsen, **3D Multiresolution Velocity Model Fusion With Probability Graphical Models,** Bull Seismological Society Am., In press,

4b Zheng Zhou, Peter Gerstoft, and Kim Olsen, Graph-learning Approach to Combine Multiresolution Seismic Velocity Models, J Geophys Research, submitted 15 Aug

4c Zheng Zhou, Peter Gerstoft, Kim Olsen, **Fusion of multi-resolution seismic tomography maps with physics-informed probability graphical models,** IEEE ICASSP 2024**.**

4d SSA 2023:
Abstract Title: Fusion of Multi-Resolution Seismic Tomography Maps Using Physics-Informed Probability Graphical Models
Authors: Zhou, Z., Gerstoft, P., Olsen, K. B.

4e AGU 2023:
Abstract Title: Fusion of Multiresolution Seismic Tomography Maps Using Physics-informed Probability Graphical Models
Authors: Zhou, Z., Gerstoft, P., Olsen, K. B.

4f SSA 2024:
Abstract Title: Enhancing 2D/3D Seismic Velocity Model Integration Using Probability Graphical Model
Authors: Zhou, Z., Gerstoft, P., Olsen, K. B.

4g: **2023 SCEC Annual Meeting, Abstract ID:** 13244**, Poster #267, Date:** 09/14/2022
Poster Title: Fusion of Multiresolution Seismic Tomography Maps Using Physics-informed Probability Graphical Models. Poster Presentation at 2023 SCEC Annual Meeting.
Authors: Zheng Zhou, Peter Gerstoft, and Kim Olsen

Six dense sensor arrays were deployed across the faults ruptured in the 2019 Ridgecrest earthquake sequence (see Fig. 1, left panel, A1, A2, B1 through B4). Owing to these densely distributed arrays, we computed surface wave dispersion inversion profiles for station pairs. Subsequently, we aggregated them to derive HR 2D vertical S-wave velocity models Zhou et al. [2022], as illustrated in Fig. 1 (top right). These derived models are compared with vertical cross-sections extracted from 3D models and combined with the LR background model (from the SCEC CVM-4.26) through various fusion methodologies. For instance, the B2 and B4 array panels (Fig.~1c, d) depict the 2D cross-sections extracted from the 3D DL fusion model and the 3DPGM, respectively. The performance of our 3D PGM approach is evident in its ability to define and preserve the accuracy of the boundary of the low-velocity zone more precisely. This improved accuracy can be attributed to the PGM's strategy of assigning differential weights to edges, which are oriented in various directions. In contrast, the efficacy of 3D DL is somewhat limited due to its inherent rotational invariance and the constraints imposed by a fixed patch dimension.

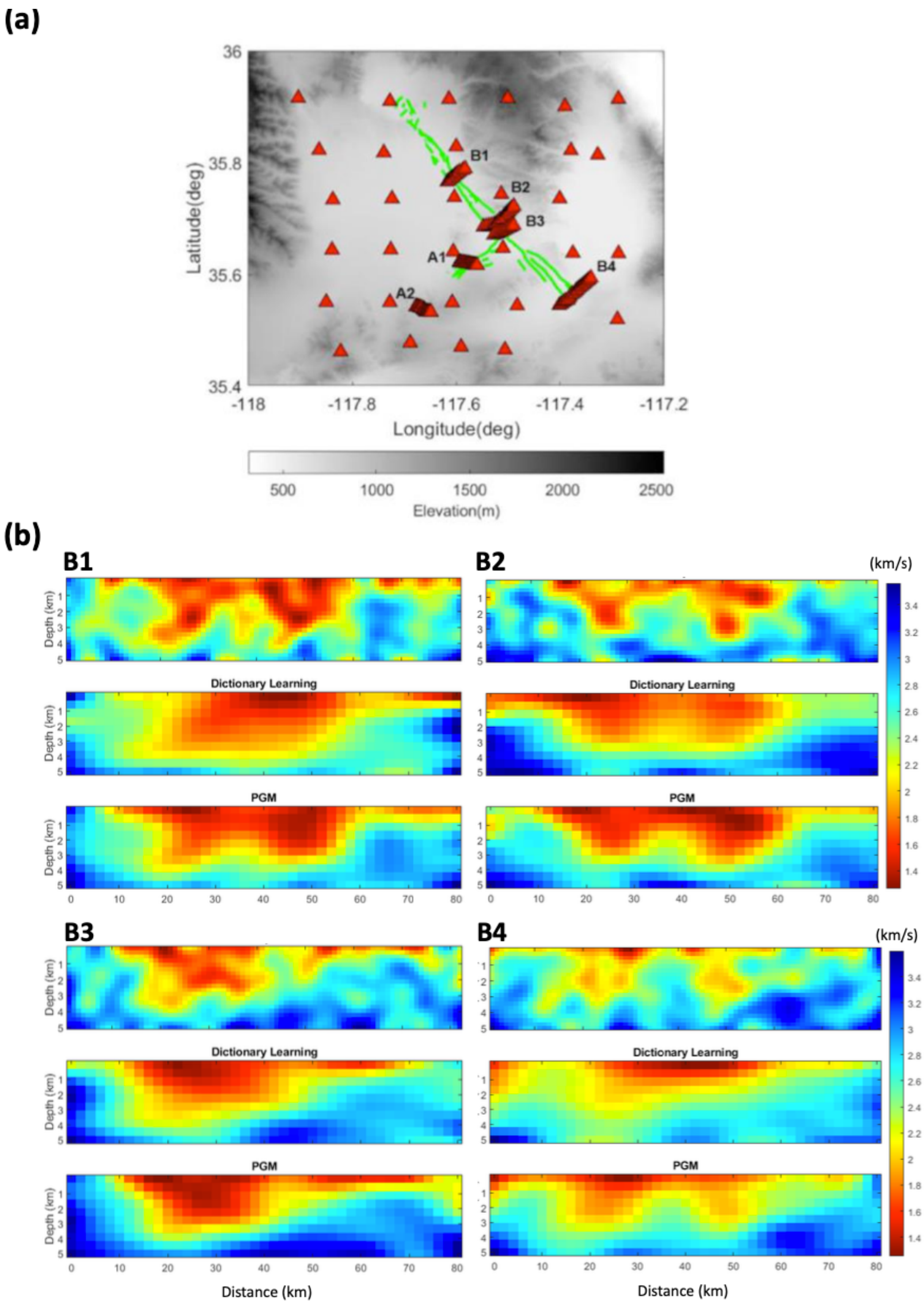

Figure 1: (a) Station locations (triangles) and main faults (lines) surrounding the Ridgecrest area. There are six dense sensor arrays across the main faults (A1-2 and B1-4). (b) Vertical cross-sections of the shear wave velocity along the B1-4 station arrays from (top) surface wave dispersion inversion, (center) the 3D fusion model from dictionary learning, and (bottom) the PGM.