

Report for SCEC Award #25189 “High-resolution imaging and earthquake locations of the Mendocino Triple Junction through Eikonal tomography and relocation by combining seismic stations and distributed acoustic sensing arrays.”

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This project investigated the potential of distributed acoustic sensing (DAS) to enhance seismic imaging and earthquake location capabilities in the vicinity of the Mendocino Triple Junction (MTJ). The study focused on the DAS array deployed near Arcata, Northern California, which operates in proximity to the tectonically complex MTJ region and overlaps with the Northern California Seismic Network (NCSN). By combining DAS measurements with conventional seismic stations, we evaluated the improvements in spatial resolution that can be achieved for tomographic imaging and earthquake relocation.

To assess the resolving power of the combined network, we conducted synthetic resolution tests using an adjoint-state Eikonal tomography workflow. Checkerboard velocity anomalies of different spatial scales (10 km, 5 km, and 2.5 km) were inverted using three acquisition scenarios: DAS-only data, station-only data, and a joint DAS-station dataset. The results demonstrate that the limited aperture of the DAS array restricts large-scale imaging capability when used alone, but significantly enhances the resolution of smaller-scale anomalies beneath and near the fiber when combined with the regional seismic network. In particular, structures smaller than approximately 10 km are better resolved in the joint inversion compared to station-only inversions.

In addition to imaging tests, we evaluated the feasibility of using DAS recordings for waveform cross-correlation measurements within P-wave windows. These measurements are critical for high-precision earthquake relocation and for extracting differential travel times used in double-difference tomography and focal-mechanism studies. Cross-correlation results from several earthquake pairs show high similarity across a broad section of the fiber, despite differences in epicentral locations. This indicates that DAS arrays can provide stable and spatially dense measurements suitable for relocation and source characterization studies.

Finally, we explored extensions of the Eikonal tomography framework to incorporate secondary seismic phases observed in DAS data, such as PS-converted phases and depth phases. These phases provide additional sensitivity to velocity structure at depth and may improve imaging of key tectonic features. Synthetic experiments illustrate the sensitivity kernel associated with PS-converted phases for a model containing a low-velocity anomaly representative of fluid accumulation at a subduction interface. Such anomalies are thought to influence slip behavior in subduction systems, making them a relevant target for future studies in the MTJ region.

These analyses support the scientific potential of the recently expanded DAS deployment in the Arcata region, which has been recording continuously since late 2025. The extended array provides a unique opportunity to integrate dense fiber-optic measurements with existing seismic networks to improve earthquake detection, relocation, and high-resolution imaging of the complex tectonic environment of the Mendocino Triple Junction.

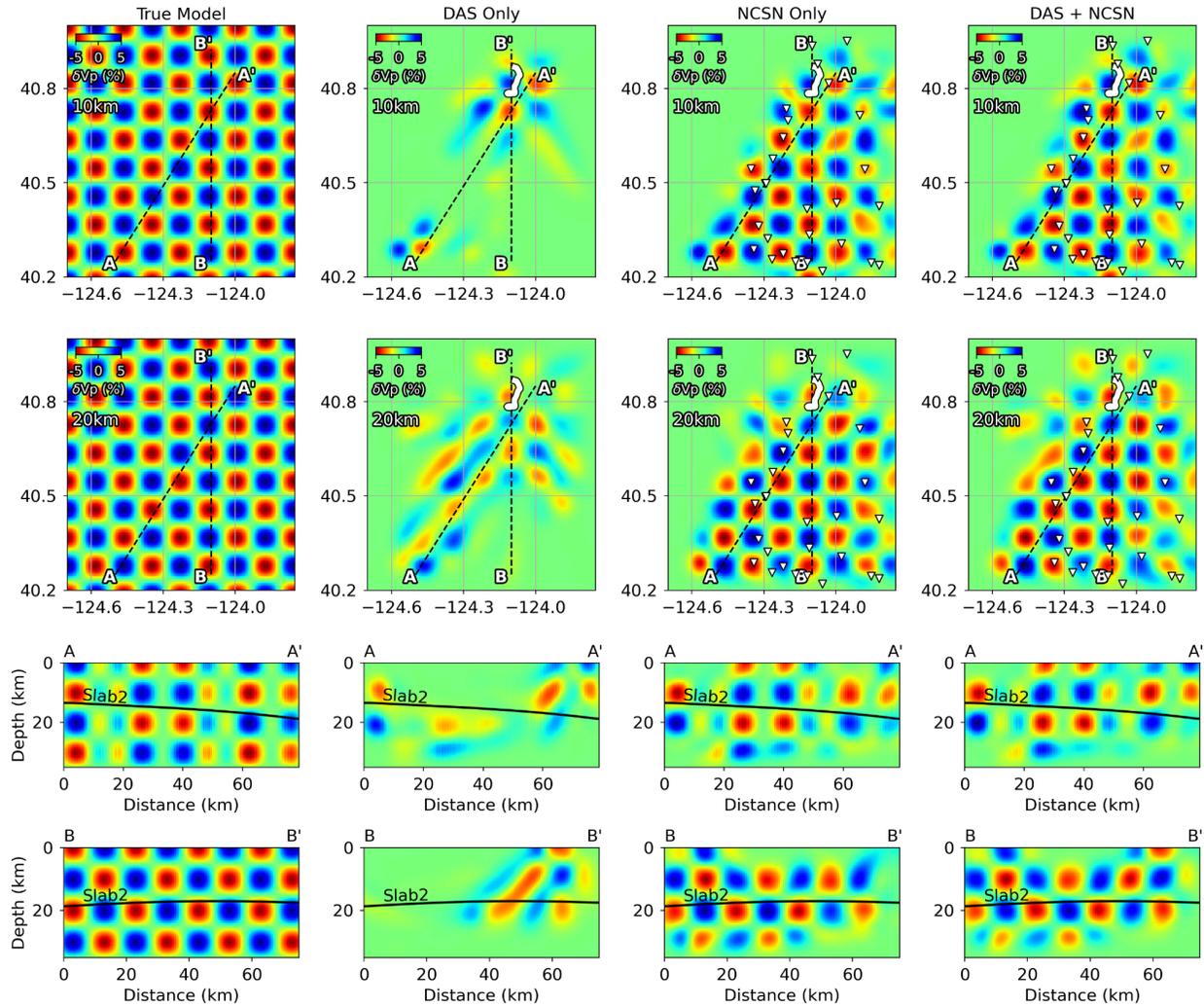


Figure 1: Checkerboard resolution test with 10-km-scale velocity anomalies. Columns show (from left to right) the input model, the inversion using DAS-only travel times, the inversion using NCSN stations only, and the joint DAS + station inversion.

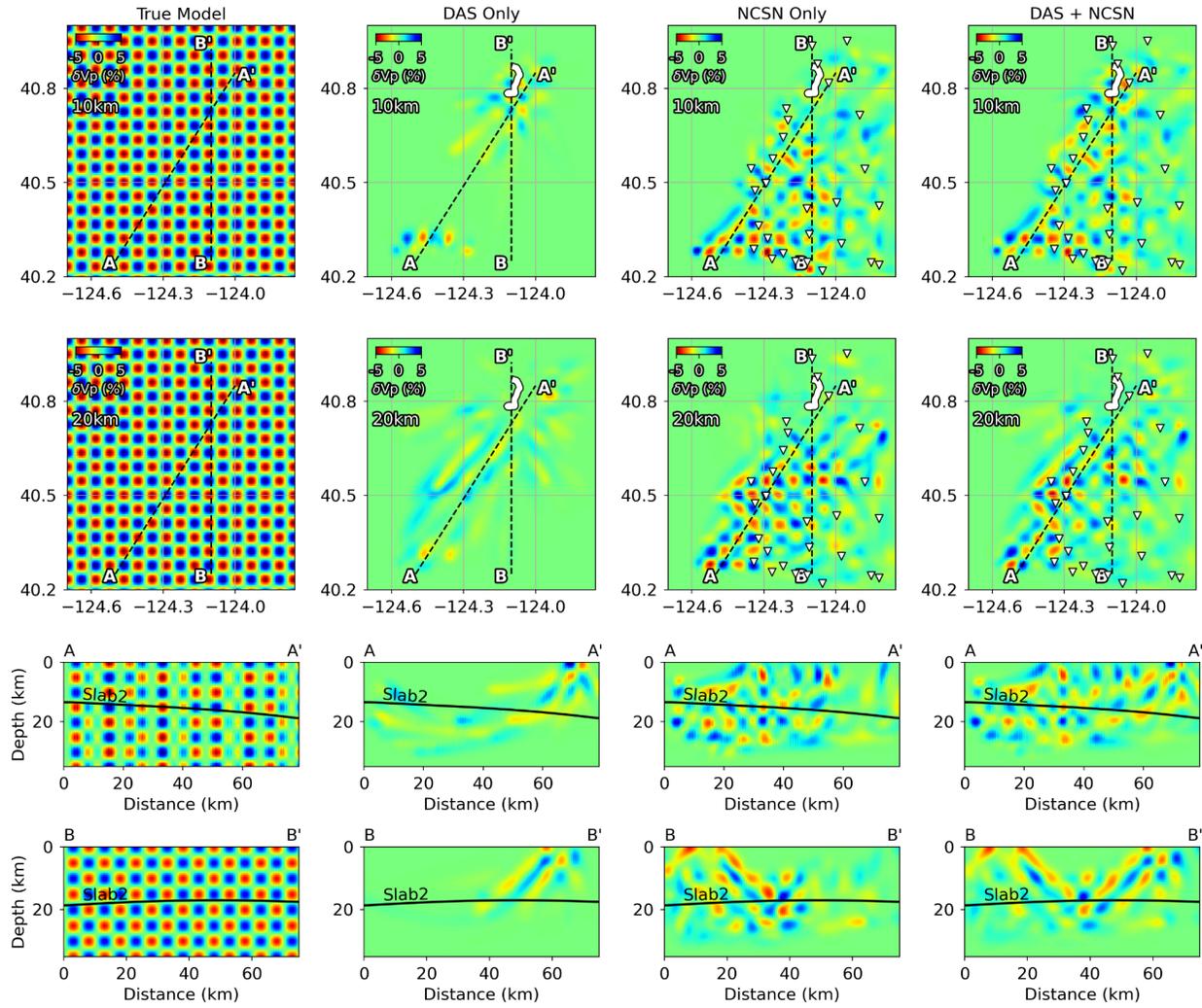


Figure 2: Checkerboard resolution test with 5-km-scale velocity anomalies. Columns show (from left to right) the input model, the inversion using DAS-only travel times, the inversion using NCSN stations only, and the joint DAS + station inversion.

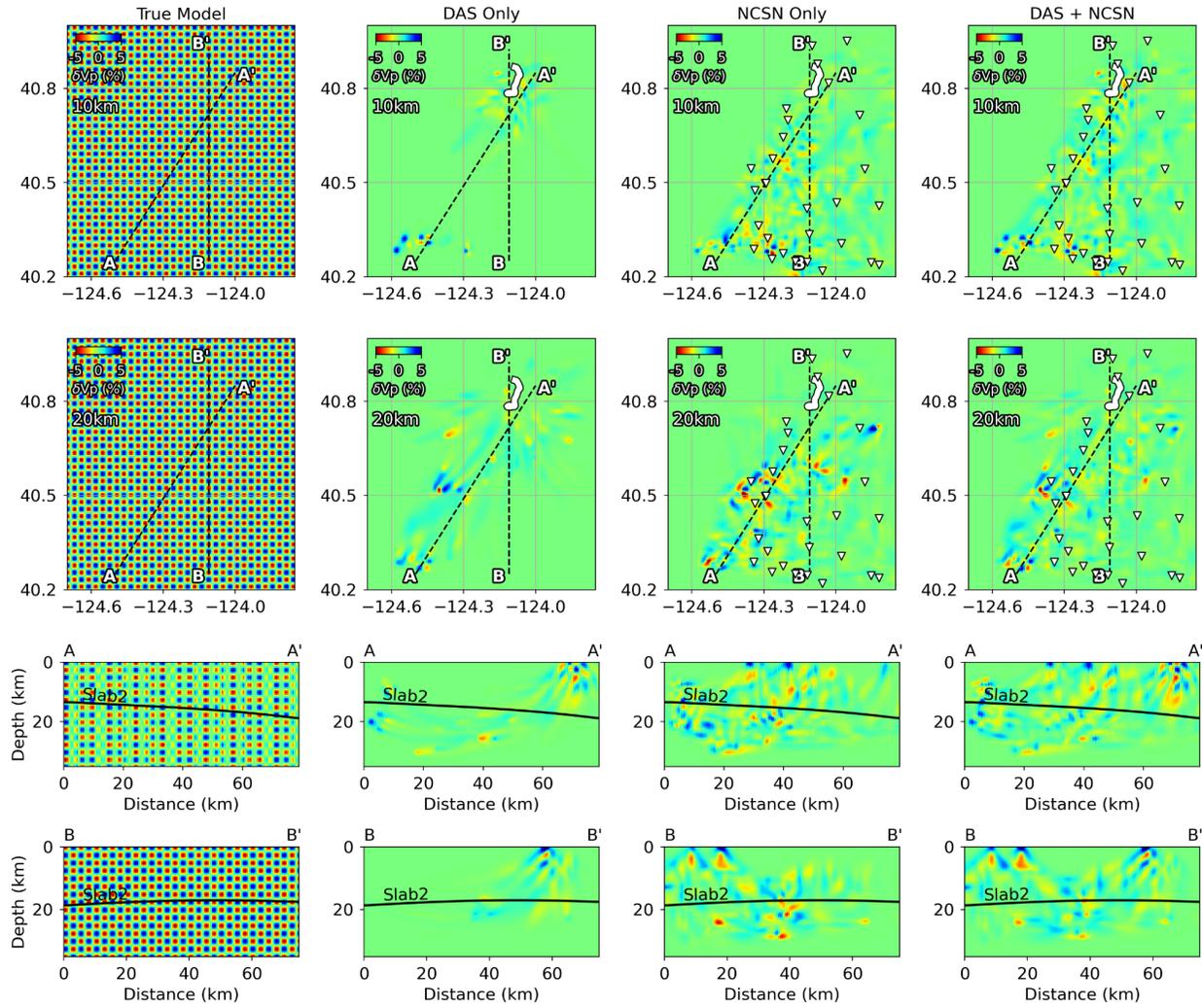


Figure 3: Checkerboard resolution test with 2.5-km-scale velocity anomalies. Columns show (from left to right) the input model, the inversion using DAS-only travel times, the inversion using NCSN stations only, and the joint DAS + station inversion.

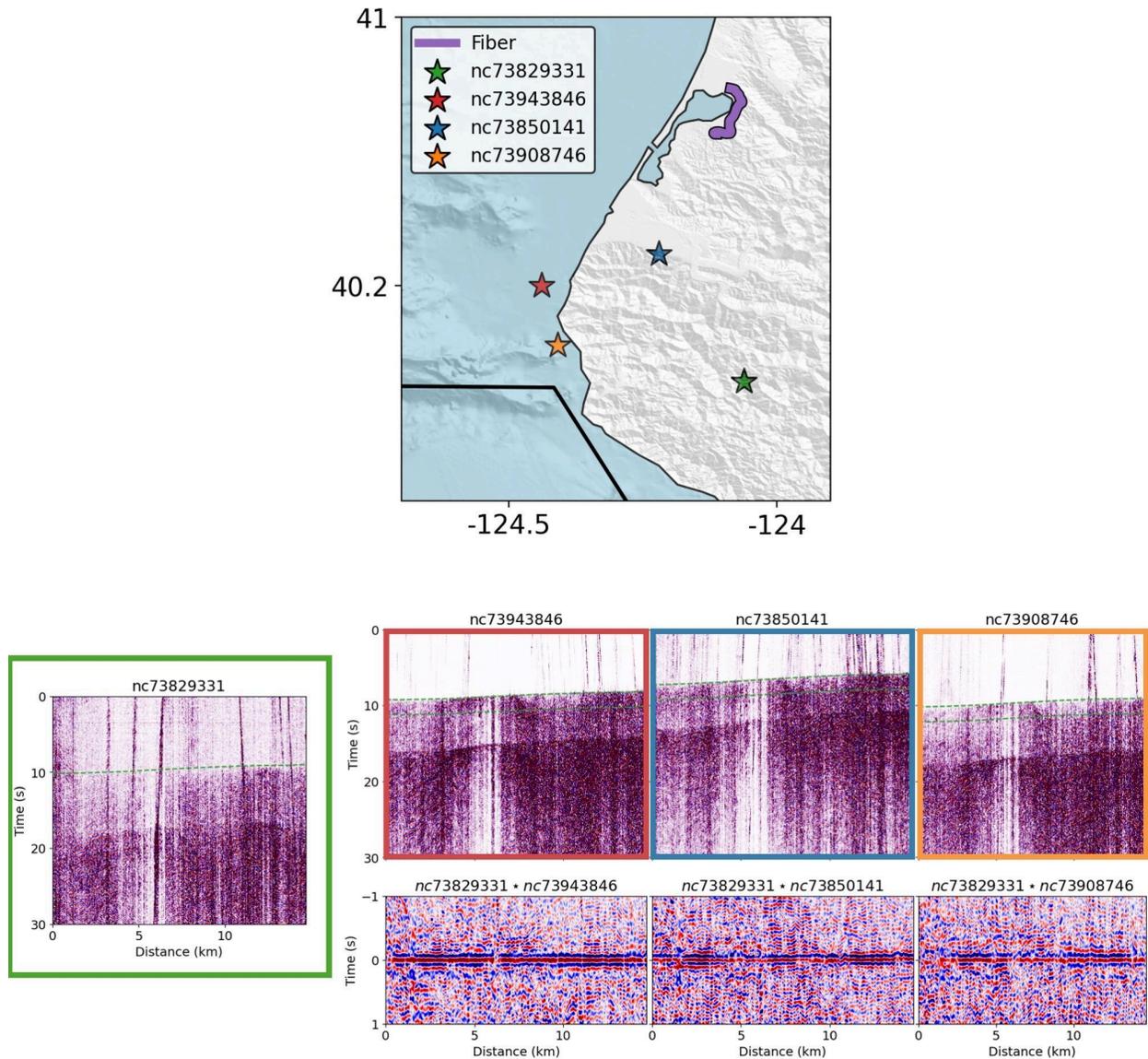


Figure 4: Examples of P-wave window cross-correlations between a template earthquake (event nc73829331, green box) and nearby events. The map indicates event locations relative to the DAS fiber. Lower panels show DAS waveforms and the corresponding cross-correlation functions. Dashed lines indicate the picked P-wave arrival times, and the second sub-horizontal line marks the end of the P-wave correlation window. High correlation values across the array demonstrate the suitability of DAS recordings for differential travel-time measurements for relocation and source studies.

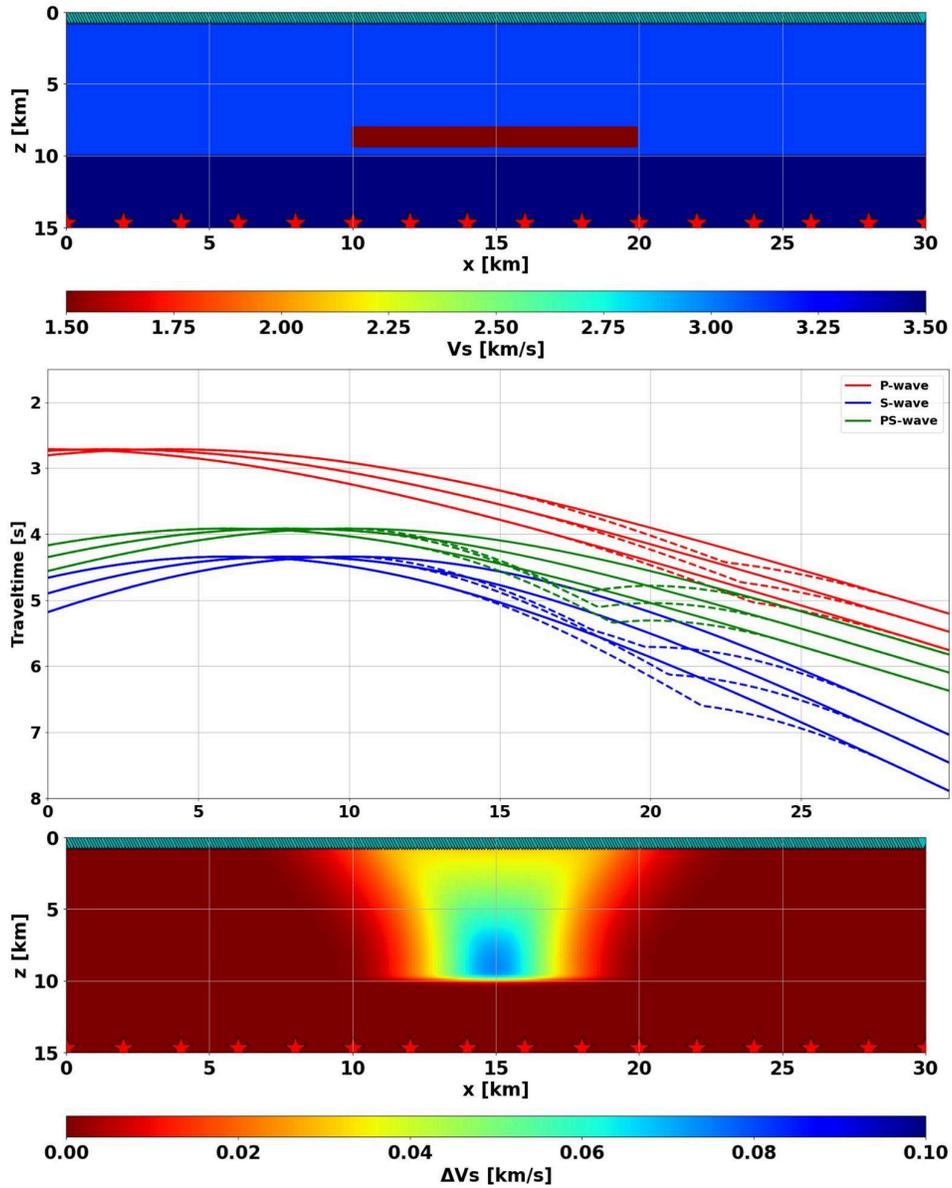


Figure 5: Synthetic example illustrating the sensitivity of PS-converted-phase Eikonal tomography. Top panel: S-wave velocity model used to generate synthetic travel times, including a low-velocity anomaly (1.5 km/s). Middle panel: example travel-time curves for P, S, and PS phases. Bottom panel: sensitivity kernel for PS-converted-phase tomography, showing how such phases provide sensitivity to velocity variations at depth, potentially associated with fluid accumulation near the slab interface.

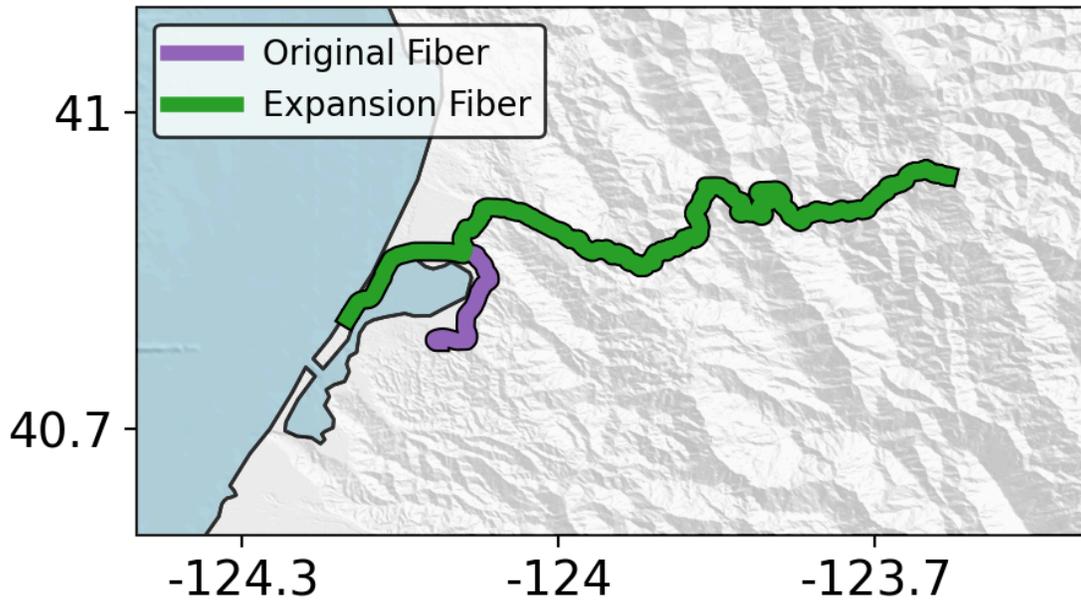


Figure 6: Map of the expanded DAS array near Arcata, California, showing the original USGS fiber deployment (purple) and the recent extension (green). The expanded array increases spatial coverage and provides new opportunities to integrate DAS observations with regional seismic networks for improved imaging and earthquake monitoring in the Mendocino Triple Junction region.