Travel Time Tomographic Imaging of Shallow Fore-arc Basin Structure at the Cascadia Subduction Zone Offshore Washington

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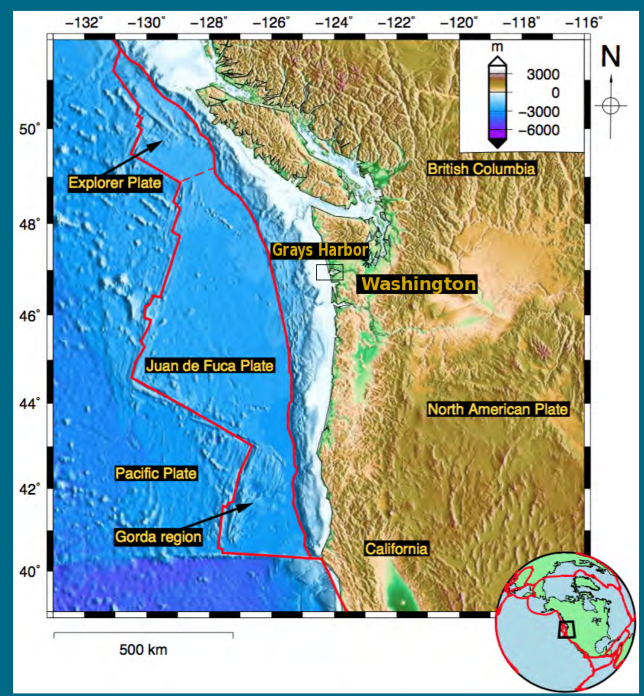
Introduction

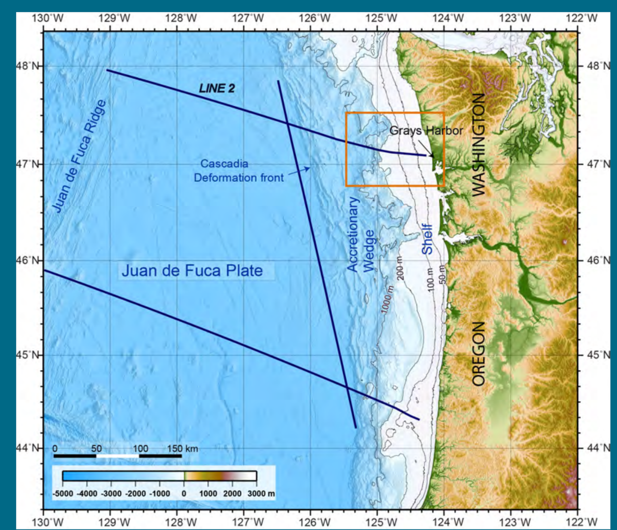
The Cascadia subduction zone (CSZ) where the very young (late Miocene, ~10 Ma old) oceanic crust of Juan de Fuca (JdF) plate is being subducted beneath the overlying North American continental plate, extends 1100 km from the Mendocino Escarpment off northern California to northern Vancouver Island.

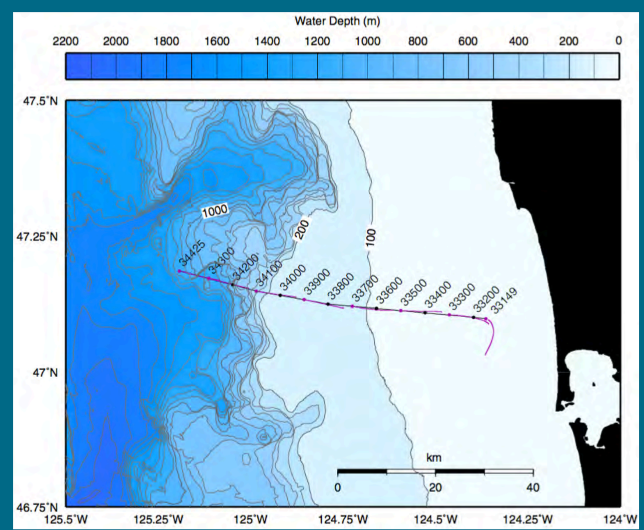
The convergence rate varies from 30 mm/y at the southern end of the plate boundary to 45 mm/y at its northern end. Even though the relatively short documentary history (late eighteenth century) dose not provide any written record to estimate the size and recurrence interval of earthquakes at Cascadia, geological evidences suggest the potential capability of generating Magnitude ~ 9.0 earthquakes.



The probability of occurrence of a giant earthquake in the future not only poses major seismic and societal hazards to populations of the Pacific Northwest but would cause tsunami damages across the Pacific Ocean. It is therefore of particular interest to gain insight into the structure and asses the seismo-tectonic behaviour along this margin. The knowledge about the geometry and properties of the plate boundary, the hydration state of the descending oceanic plate and the amount of subducting sediment are thus of fundamental importance. Focused geophysical studies continue to advance our understanding of Cascadia margin.

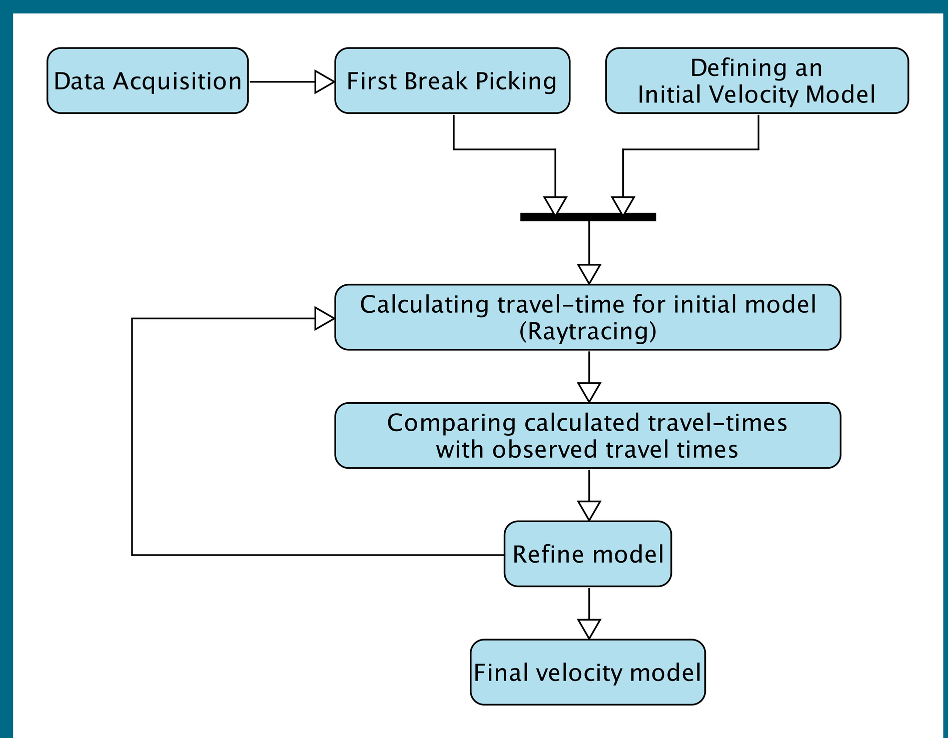
The Cascadia Ridge to Trench study was designed to characterise the structure and evolution of the JdF plate and to test the hypothesis that the JdF plate is significantly hydrated prior to subduction, transporting water into the subduction zone, and contributing to along-strike variations in structure and seismicity along the Cascadia margin. The experiment included two East-West transects extending from the JdF ridge to the accretionary wedge and shelf of the Cascadia margin and a long trench-parallel line outboard of the Cascadia accretionary wedge.



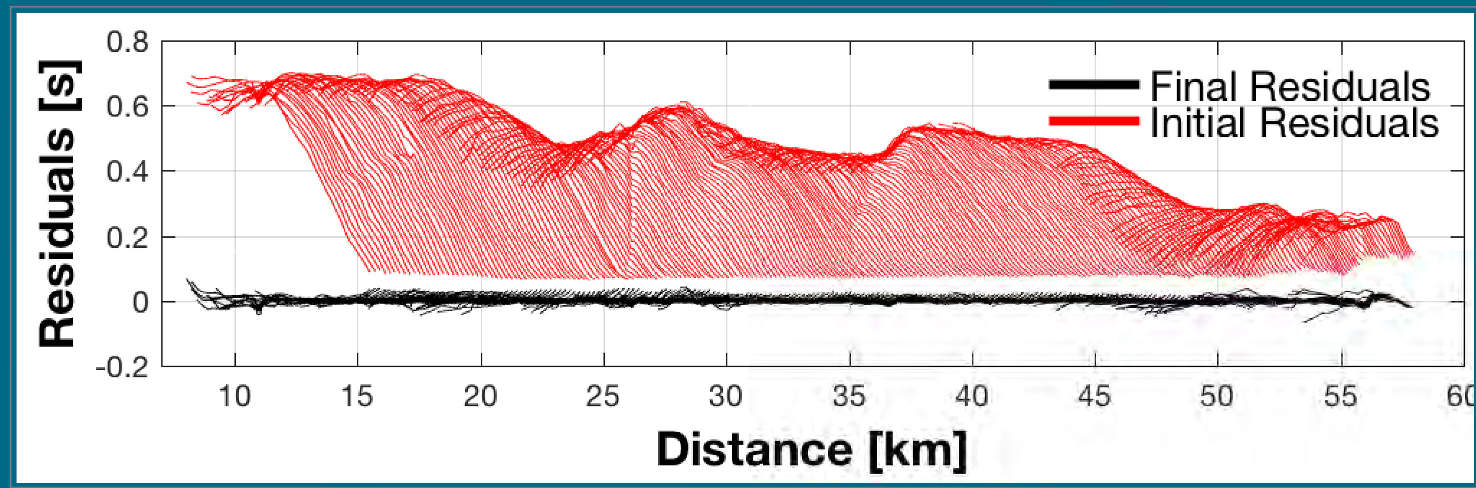


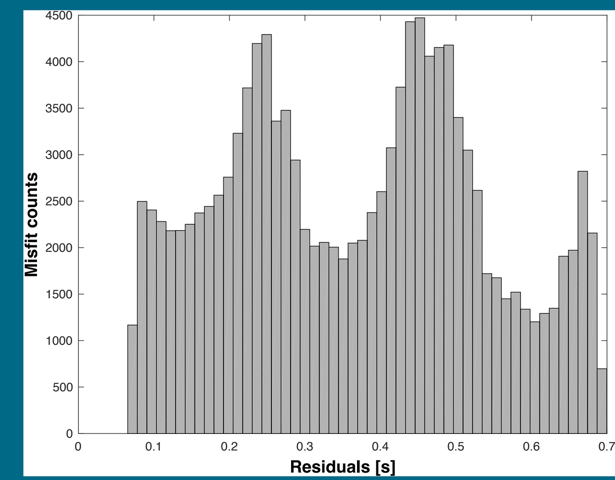
Methods

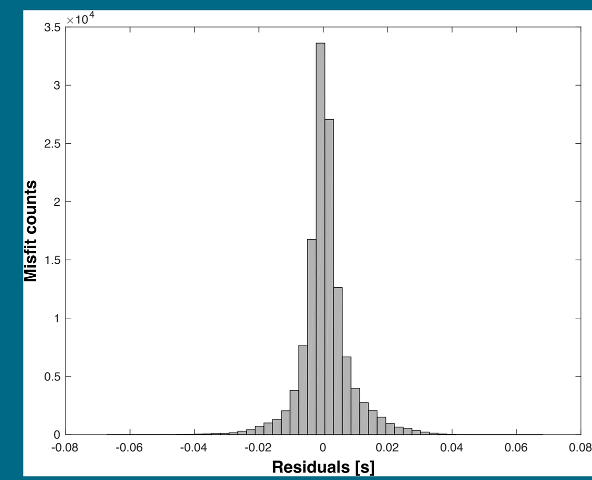
We conduct a P-wave tomography study of shallow fore-arc basin structure at the Cascadia subduction zone using first-arrival travel times from two multi-channel seismic (MCS) profiles acquired with an 8-km long streamer in the frame of the 2012 Cascadia Ridge to trench program. The first profile extends offshore Gray's Harbor in Washington and the second extends offshore Oregon at the latitude of Hydrate ridge, with the fore-arc basin imaged below ~60 and ~70-km long shallow water (< 500 m) portions of these profiles, respectively. We use the travel time tomography method of VanAvendonk et al. [2004], which is based on the shortest path method for ray tracing, and iterative inversions driven by gradual reduction of the chi-square misfit (root mean square value of the difference between predicted and observed travel times normalized by pick uncertainty). We construct our starting model by hanging to the seafloor a 1D velocity profile based on interval velocities derived from semblance analysis of MCS data.

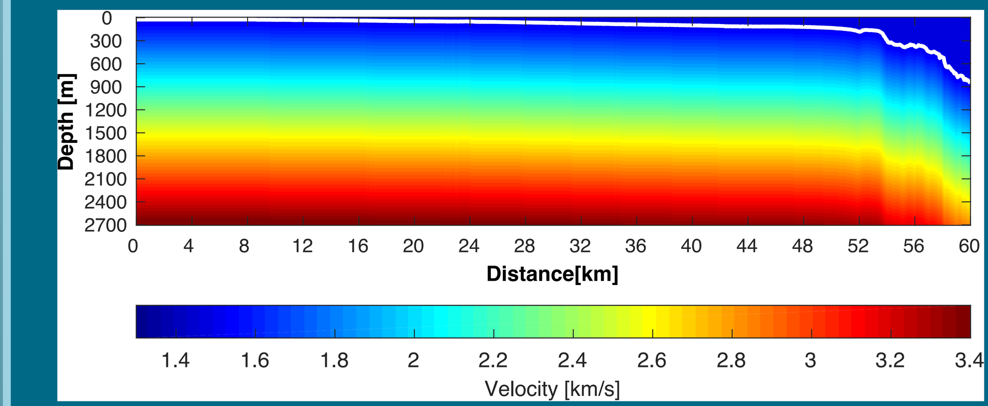


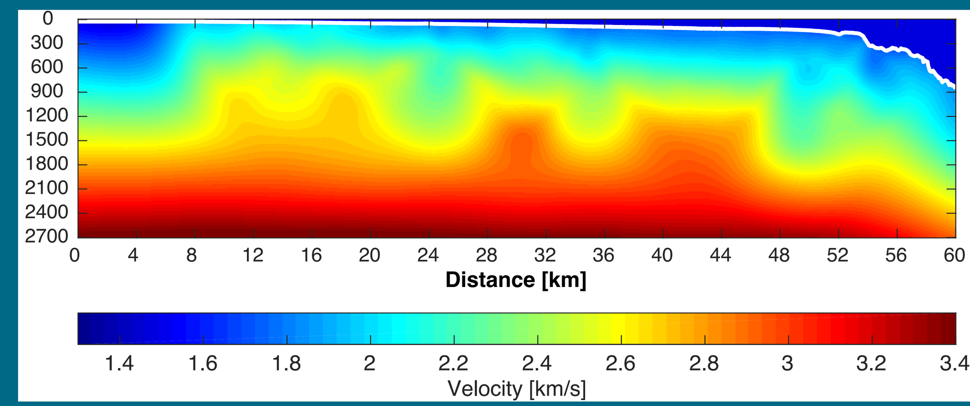
Below: Travel time misfit plots (the difference between the observed (picked) travel times and the predicted travel times), and histogram of the distribution of residuals before (left image) and after (right image) inversion.





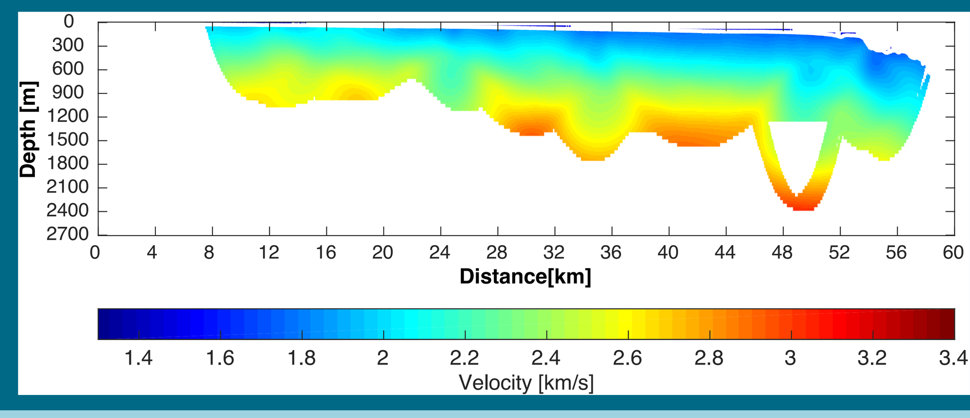


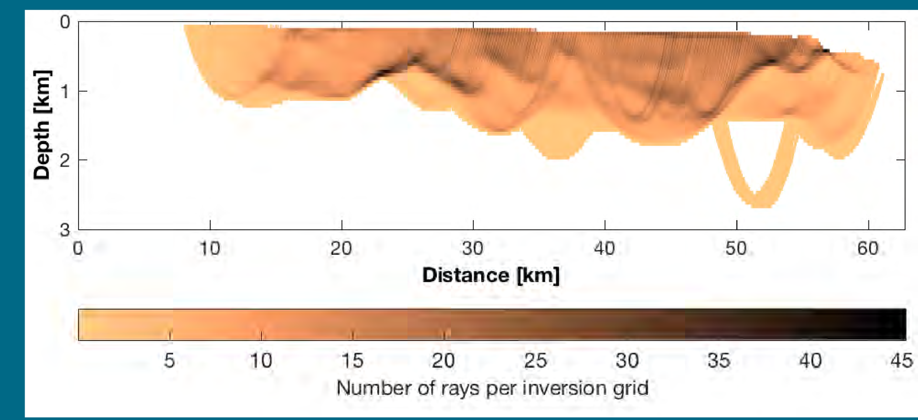




Above: Laterally homogeneous starting velocity model and tomographic inversion result (Final model).

Right: Final model restricted to the ray covered area.

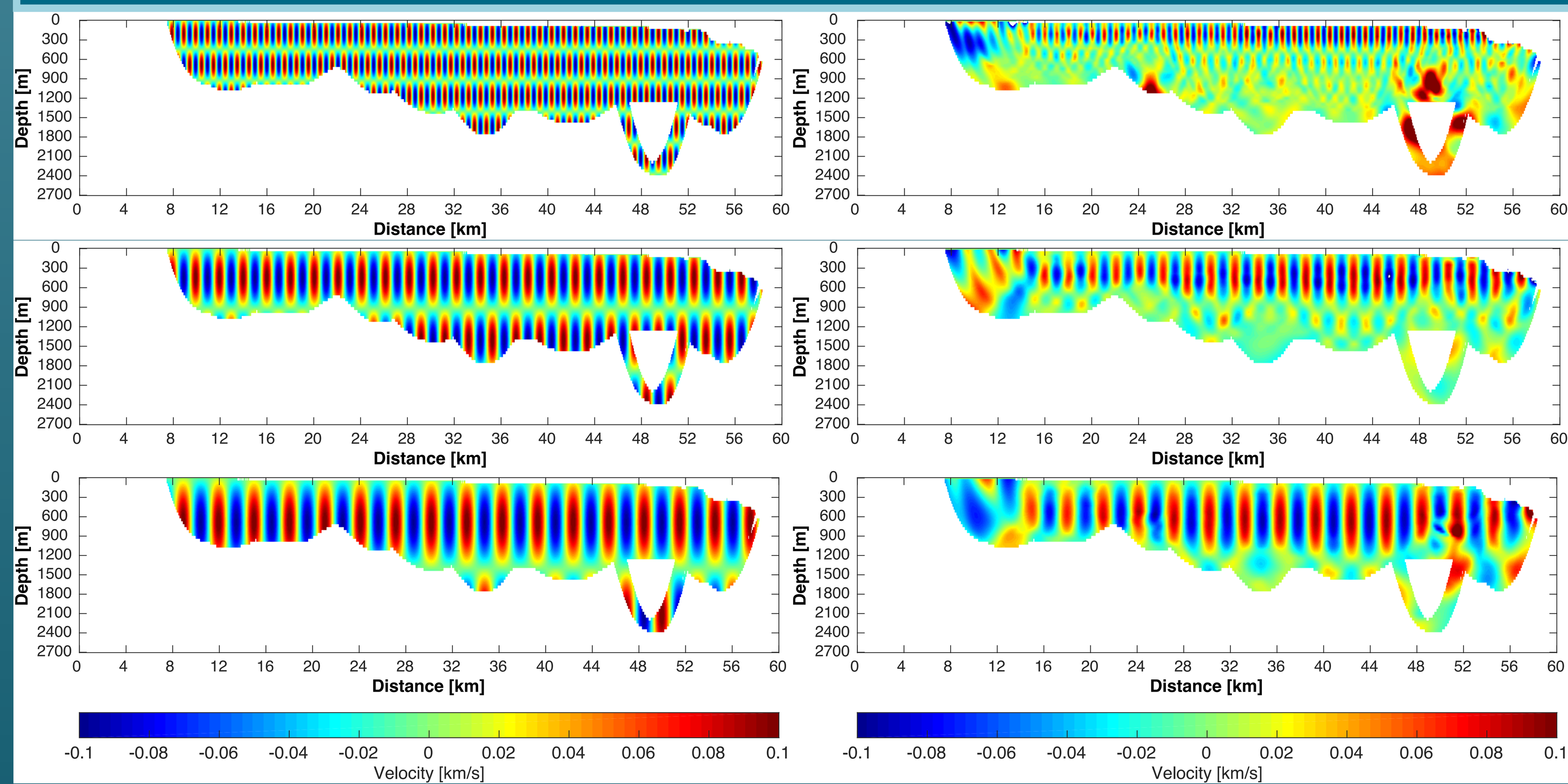


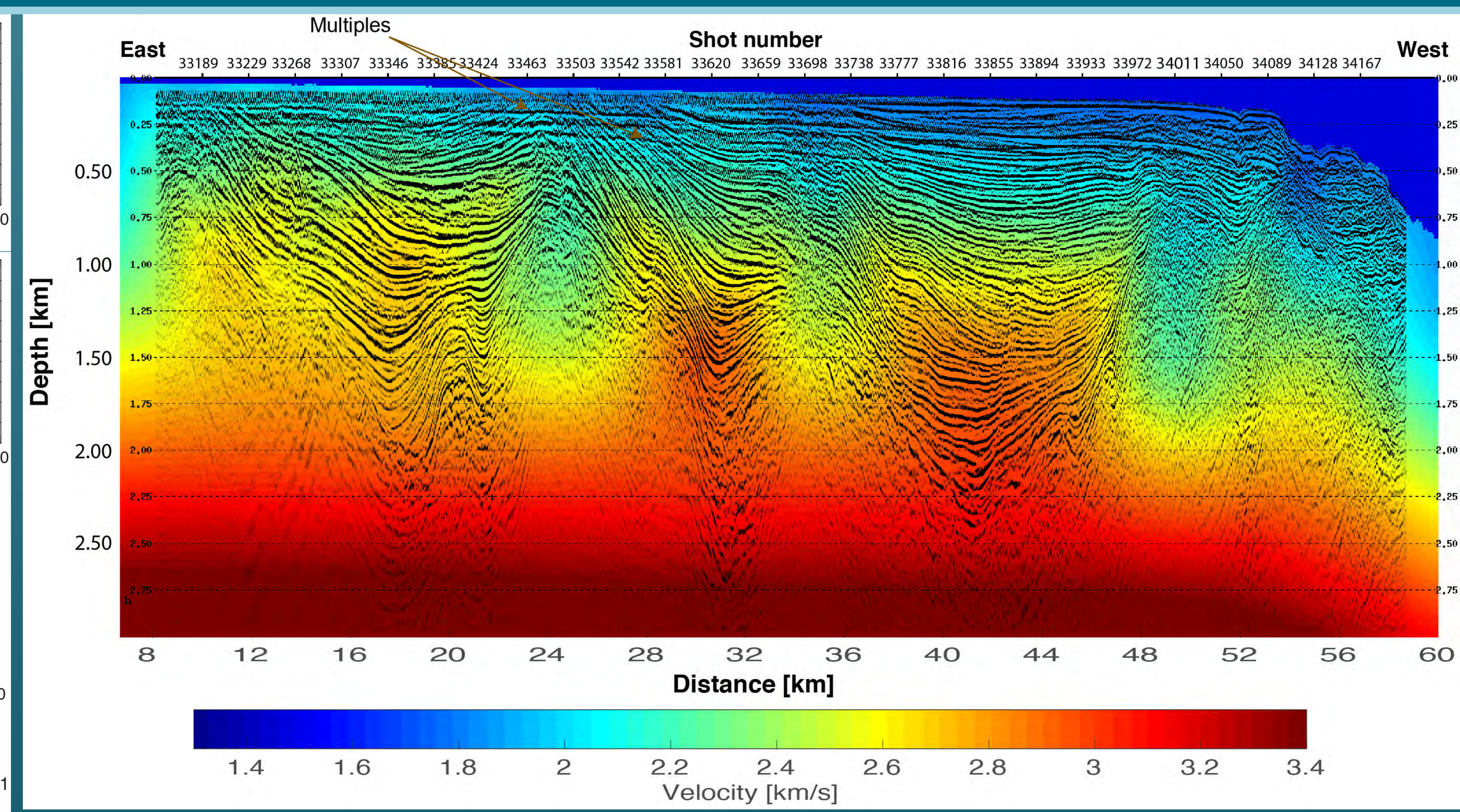


Above: The derivative weight sum (DWS) for the best-fit model. The colour-bar represents the number of rays per inversion cell. Note a good coverage in central and shallow parts (reliable regions for interpretation). Regions associated with lighter colour (toward the edges and deeper parts) are not well resolved.

Results

Below left: Resolvability of the final model is assessed using checkerboard pattern tests with different anomaly sizes. We then compare our tomographically-derived velocity models to coincident seismic reflection images post-stack time migrated and converted to depth using our results (below right). On the Washington shelf, where the fore-arc basin is segmented into three sub-basins, ray coverage mostly extends to ~1.2–1.5 km below seafloor. Velocities in the shallowmost sediments show, at the large scale, a gradual decrease towards the shelf edge (from 2.1 to 1.8 km/s). At depth, regions devoid of clear reflections such as an ~5 km large anticline core are associated with lower velocities than that obtained within mildly deformed sedimentary layers on either side (2.3 vs 2.7 km/s, measured at 1.2 km depth), suggesting the presence of localized fluid-rich regions within the basin.





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