Response to reviewers

We express our sincere gratitude to the reviewers for their insightful feedback and thoughtful suggestions, which have significantly improved the quality of our report. Below, we provide our responses (in blue) to each of the reviewers' comments (in black).

Editor

There are some concerns with how this model fits within the ecosystem of CASIE21 models that needs to be addressed prior to publication (e.g., Reviewer B comments).

Author's response: We understand the concern regarding the integration of our model within the broader CASIE21 framework. This issue raises an important point about cohesion with prior and current efforts, and we have made several revisions and clarifications in the manuscript to address this.

Our intention is not to override or diminish the utility of the CASIE21 models but to build upon them for a different objective. While CASIE21 provides valuable high-resolution imaging of the basement, our goal is to construct a margin-wide Moho interface that supports regional geophysical modeling, inversion workflows, and community velocity model (CVM) development. To emphasize this, we have revised the **Introduction** to articulate the goals of this study. We have also clearly detailed how we achieved this goal by (1) developing a coherent and adaptable Moho model using publicly available datasets, and (2) presenting an open-source, reproducible workflow implemented in MATLAB that enables flexible data integration and accommodates future refinements as new data become available.

We also recognize the reviewer's concern about alignment with ongoing CASIE21 and related efforts. Prior to submission, we consulted with several members of the CASIE21 team and understood that key slab structure datasets are still in development and not yet publicly released. While these forthcoming results will provide critical constraints for future iterations, we believe there is immediate value in releasing CascadiaMoho1.0 now to address the community's need for a baseline margin-wide Moho model. Therefore, consistent with Seismica and CRESCENT policies, we have excluded unpublished findings from this version and will incorporate such results in CascadiaMoho2.0.

To further underscore these points, we have revised the final paragraph of the **Results and Future Directions** section to explain our approach to data gaps, justify our modeling choices (such as slab thickness assumptions), and outline the roadmap for future improvements based on CASIE21 results and other community data.

We hope these clarifications address the reviewer's concerns and affirm that our model is complementary to CASIE21 efforts, serving a distinct but interconnected purpose within the broader ecosystem of CSZ research.

Reviewer A

Minor Comment 1

Lines 20–21: “lower boundary (called the 'Moho') of the tectonic plate.”
I would not refer to the Moho as the lower boundary of the tectonic plate. I suggest using ‘crust–mantle boundary’ or similar terminology.

Author’s response: We agree and have replaced the ‘lower boundary’ with ‘crust-mantle boundary’.

Minor Comment 2

Lines 24–25: “Missing information offshore California was filled in by estimating from existing data.”
This statement is rather vague and difficult to interpret without reading the full manuscript.

Author’s response: The referred sentence is in the non-technical summary of the report. In response to the reviewer's feedback, we have identified areas in the summary where clarity could be improved and subsequently rewrote those sections to enhance understanding for the reader.

‘Non-technical summary
Understanding the shape and depth of the oceanic tectonic plate as it sinks beneath North America in the Cascadia region is important because it helps explain where earthquakes happen, how volcanoes are fed, and how to better assess seismic risks. Here, we present a detailed and unified view of the crust–mantle boundary (known as the Moho) of that diving oceanic plate along the Cascadia region. To create this view, we combined highly detailed offshore seismic images from a recent marine expedition with previously published onshore models. By merging these datasets, we produced six different versions of the Moho that other researchers can choose from based on the needs of their own studies. Our method offers a simple, flexible and open-source workflow to combine different types of data, and scientists can adjust the settings to create a version that fits their specific study. In some areas where no data exists, we estimated the Moho location using nearby information. The result is a set of comprehensive models that describe how the structure of the subducting slab varies along the Cascadia margin.’

Minor Comment 3

Figure 1: I recommend replacing ‘crustal topography’ with ‘top of igneous crust surface’ as used in Carbotte et al. (2024). I personally find scales with non-rounded values (e.g., 3.8, 5.6 km) less effective. I would suggest using rounded values such as 2.5, 5 km, etc., for the top of the crust. It would also be helpful to label some of the contours. In the legend, the red circle used to denote “the stations to calculate receiver functions” is unclear; I would suggest using squares instead.

Author’s response: We have implemented all the suggested changes in figure 1.

Minor Comment 4

Line 49: "high uncertainty in the nearshore region" . Please, consider adding a quantitative estimate here.

Author's response: We have added values to this estimate for better clarification in the revised manuscript -
'exhibit high uncertainty (mostly around 2-4 km) in the nearshore region'

Minor Comment 5

Line 52: I would avoid using "seafloor basement" here as the basement does not outcrop at the seafloor offshore Cascadia.

Author's response: We have removed the word 'seafloor'.

Minor Comment 6

Line 65: Please cite Figure 1 here, as it shows the track lines of the CASIE experiment.

Author's response: We have now added the citation to Figure 1 in this line.

Minor Comment 7

Line 69: "This CASIE21 dataset is also supplemented with 750 km of MCS." Are all three MCS lines included? I see only one in Figure 1.

Author's response: We thank the reviewer for raising this important point. Not all MCS lines from ridge to trench study are in the CASIE21 dataset, only the southern one is. For better clarity we have rephrased this sentence -

'The CASIE21 dataset is further complemented by MCS data collected over the Juan de Fuca (JdF) plate, spanning from the JdF Ridge to the trench offshore of Oregon (Han et al., 2016).'

Minor Comment 8

Line 72: When were these stations operating? I also recommend adding the term "broadband" to describe the seismic stations.

Author's response: We have chosen not to include additional details about the stations, as this information is already thoroughly presented in Bloch et al. (2023). However, in response to the reviewer's suggestion, we have incorporated the term "broadband".

Minor Comment 9

Line 73: Consider adding "oceanic" before "Moho."

Author's response: We have rephrased it to 'Moho of the oceanic plate'

Minor Comment 10

Line 74: “nominal depth uncertainties” ; Although you discarded data of lowest quality, providing an overall uncertainty estimate would be helpful.

Author’s response: In response to the reviewer’s comment, we have included detailed uncertainty estimates for most of the datasets used in our Moho model development. These details have been added to the **Data** section of the manuscript.

Below are the details we have added for each dataset,

CASIE21 dataset (Carbotte et al., 2024)

‘Depth uncertainty, in this dataset, varies with location and data quality. In the outer 20 km seaward of the deformation front, where MCS data are densest and reflectors are well-imaged, slab surface depths are accurate to within 50–100 m. Within the outer accretionary wedge, uncertainty increases modestly to 100–300 m due to slightly weaker reflections and reliance on reflection tomography. Beneath the continental shelf, where reflections degrade and velocity structure becomes harder to constrain, errors grow to 300–900 m.’

(Bloch et al., 2023)

‘In this dataset, vertical errors are smallest (2-3 km) in Central Oregon. Uncertainty grows to 3-5 km beneath the Olympic Peninsula and Vancouver Island as thick sediments, shallow dip, and 3-D velocity variations blur the receiver-function phases. Uncertainty in the southern Klamath/Cape Mendocino segment, imaged by a sparser network in tectonically contorted crust, reaches 5–7 km. Offshore portions that rely on artificial control points, and downdip regions where the slab signal vanishes, exceed 7–10 km because depth is effectively extrapolated rather than observed.’

(McCrory et al., 2012)

‘The uncertainty in this dataset varies by region and data quality. In well-constrained areas like northern California depth uncertainty is low, around 2–3 km. In regions like Puget Sound and Vancouver Island, differing interpretations between passive and active seismic data lead to uncertainties of 4–8 km. Oregon, with sparse data and large interpolation gaps, has much higher uncertainties of 8–10 km. Offshore Oregon areas, constrained only by trench geometry and assumed sediment thickness, exceed 10 km uncertainty. These variations stem from uneven data coverage, velocity model biases, and ambiguity in mapping the true slab surface.’

Minor Comment 11

Line 71 and 94: As mentioned earlier, I have not worked in Cascadia, so I’m not sure how to evaluate these three onshore slab models and their respective uncertainties. Are these models used interchangeably by the community? It might be useful to include a few sentences outlining the pros and cons of each. From the literature, it appears that McCrory et al. (2012) is more widely used than Slab2.0.

Author's response: We prefer not to highlight the specific strengths or limitations of existing models. The slab depth information from McCrory et al. (2012) is widely used due to its simplicity, broad-scale accuracy, and long-standing availability. Slab2.0 incorporates the McCrory et al. (2012) dataset, along with additional data sources, and applies its own filtering and smoothing procedures. The objective of this initial version of CascadiaMoho is not to promote a single dataset, but rather to provide users with the flexibility to choose among multiple dataset combinations based on their specific research needs.

Minor Comment 12

Line 101 - 102: "Basement depths were converted to Moho depths by assuming a 6 km average slab thickness of the oceanic slab." Several seismic profiles showing the Moho of the oceanic crust are presented in Carbotte et al. (2024); this reference could support this statement.

Author's response: We have added the suggested reference to this sentence.

Minor Comment 13

Figure 2: Again, I suggest using a scale with regular intervals (e.g., 8–28 km in steps of 2 km) and annotating some contours. It appears that, after smoothing, the slab is shallower in the central portion (near the deformation front) than shown in Figure 3. I am not sure why this is.

Author's response: We have updated the colorbar in Figure 2 to enhance clarity and make it more reader-friendly.

Regarding the differences between Figures 2 and 3, we would like to clarify that the smoothing applied to the CASIE21 data did not cause any specific region to appear shallower or deeper. Rather, the high-resolution roughness of the original basement topography was simply smoothed out, without introducing any significant depth changes.

Minor Comment 14

Line 151: Please refer to Figure 4 here.

Author's response: We have added the figure reference to this sentence.

Minor Comment 15

Line 149 - 151: "To address this gap, we extend the across-strike profile derived from the southern portion of the polygonal-fit Moho model up to the southernmost extent of the subduction zone, between 40.5° and 41.5° latitude." Please indicate why this assumption is considered valid.

Author's response: While imaging efforts are ongoing in offshore Northern California (Shuck et al., 2024), the results are at least a year away from being released. In this paper, we have chosen to include only information that is publicly available. It is our intention to incorporate those results in a future update or iteration of this combined Moho interface. However, given the pressing need for a comprehensive Moho interface to support testing and development of various geophysical models, we proceed using the best available data at this time. To address the current data gap, we have interpolated from the nearest regions where reliable data exist.

Minor Comment 16

Line 152: "Given the minimal sedimentary cover in this area, the bathymetric data effectively represents the basement topography." It would be helpful to provide a reference to support this statement.

Author's response: To address this we have included the following reference to the sentence mentioned.

Gardner et al. Map showing sediment isopachs in the deep-sea basins of the Pacific continental margin, Strait of Juan de Fuca to Cape Mendocino. Technical report, US Geological Survey, 1993

Minor Comment 17

Discussion: It might be useful to provide masks along with the Moho depth files to indicate where major interpolation or extrapolation was performed. This would help future users understand where to limit their interpretations.

Author's response: We appreciate the reviewer's suggestion regarding the inclusion of masks with the data product. However, we would like to clarify that including masks may undermine the core objective of this work, which is to present a coherent and continuous Moho surface across the entire region. This aligns with the broader goal of the paper: to provide a Moho model that can be readily used in geophysical studies and refined further in future efforts. We have clearly indicated areas with and without data coverage in both the figures and the text. Additionally, the accompanying code enables users to easily extract and work with specific subsets of the region, allowing them to tailor the Moho interface to their needs. Looking ahead, we plan to include uncertainty estimates for the provided data points in the next version of the combined Moho interface, further enhancing its utility and transparency.

Minor Comment 18

Line 168: There may be more recent refraction studies constraining oceanic crustal thickness such as Han et al. (2016) and Horning et al. (2016).

Author's response: Studies on the thickness of the oceanic crust, based on data from the CASIE21 marine expedition, are currently ongoing but have not yet been published. We plan to incorporate these results into a future version of the model once they become available.

Minor Comment 19

Line 170:"Where datasets, such as seismic reflection data obtained during the CASIE21 marine expedition, provided information only on the top of the subducting slab..." I don't think it's accurate to say the CASIE21 marine expedition provided only information on the top of the subducting slab. While published work to date may focus on the top of the slab, I expect the dataset will also yield constraints on the Moho in the near future.

Author's response: We agree with the reviewer that in future the CASIE21 dataset will include Moho constraints, which are planned to be included in the next iteration of this combined Moho interface. To avoid confusion and ambiguity in the sentence mentioned by reviewer, we have rephrased it as the following:

'In cases where datasets provided information only on the top of the subducting slab we estimated the Moho depth by applying a consistent 6 km offset in the normal direction from the basement surface. Conversely, datasets that explicitly included Moho depth measurements were used directly without significant modification.'

Reviewer B

This manuscript by Ashraf and Hooft presents a 'new' continuous Moho surface by combining existing offshore and onshore constraints of the subducting oceanic slab along the Cascadia subduction zone. This scientific motivation for this is clear – there is abundant timely work on the Cascadia subduction zone, with significantly momentum in the community with the SZ4D and CRESCENT initiatives, among others. The primary need is for accurate constraints on the subducting megathrust and Moho geometry for a wide range of basic and applied scientific studies, including the assessment of earthquake and tsunami geohazards to the Pacific northwest region.

In principle, this is a good idea to create a continuous Moho surface, it would be very helpful to the community and worthy of publication. However, in practice, I have some concerns with how the model was created and how these conflict with ongoing efforts in the community, in particular by scientists who are actively working on the same goals.

Author's response: We thank the reviewer for recognizing the value and timeliness of this work within the broader context of Cascadia-focused initiatives. Our intention is to contribute a transparent, reproducible, and interim Moho surface that complements ongoing efforts, not to compete with or supersede them. We have clarified in the manuscript that CascadiaMoho1.0 is the first generation model built solely from published data, intended to support current research needs and serve as a baseline for iterative improvements as new community datasets become available.

Concern 1

Inference of Moho from slab top estimates: The authors utilize three onshore datasets, but only one—Bloch et al. (2023)—directly constrains the subducting Moho. The others, Slab 2.0 and McCrory (2012), provide limited and imprecise constraints on the plate interface, differing significantly from the high-resolution Carbotte et al. (2024) model. To infer the Moho, the authors project a surface 6 km below the slab top, assuming uniform crustal thickness. This is problematic, as crustal thickness varies regionally: Gorda (~5 km), Juan de Fuca (~6 km), and Explorer (~7 km), per ongoing work by Dr. Brian Boston. Local seamounts further complicate the assumption, and the actual Moho does not mimic these surface variations.

Author's response: We thank the reviewer for raising this important point and fully agree with the concern. While the assumption of a uniform 6 km oceanic crustal thickness has been commonly used in geophysical studies—including in geodetic modeling and tomographic imaging—it is increasingly recognized as an oversimplification. Although this approach has traditionally provided a convenient framework, it does not accurately capture the real variability in oceanic crustal thickness. The scientific community is gradually moving toward more data-driven, region-specific models that better reflect the complex structure of the subducting slab.

We have acknowledged this limitation in the revised manuscript in the last paragraph of **Results and Future Directions** section,

'Another approximation in this study is the assumption of a uniform 6 km thickness for the oceanic slab. Ongoing works utilizing CASIE21 reflection data aim to measure slab thickness more precisely by directly imaging the oceanic Moho (Boston et al. 2024). These results will enable future versions of the model to incorporate independently constrained Moho depths, reducing reliance on inferred slab-top information.'

Concern 2

Concern with idea that smoothing CASIE21 surface is the 'right approach'

(2) The second issue I have is with the idea that 'small scale roughness' in the CASIE21 plate interface grid needs to be smoothed out. The roughness is not an artifact but represents real roughness in the subducting plate from features like seamounts, fracture zones, abyssal hills, propagator wakes, bending faults, etc. I understand that the modeling community would like to generally have a surface that has similar spatial resolution crossing the shoreline. But I feel that the CASIE21 roughness is treated as an artifact or hinderance with how it is presented in the paper text. I personally think it would be better (and beneficial to our community) to include all possible detailed constraints i.e. no smoothing of CASIE21, and let the modelers smooth the surface if they need for their future applications. A detailed high-resolution dataset should not be downgraded because the others are of significantly lower resolution. It is easy and possible for someone who downloads this surface to smooth it as much as they want, but once smoothed, it is not possible to recover the original details… Perhaps this comes down to a difference in philosophical opinion between members of the community, since the debate has come up in relevant CRESCENT meetings – hence why Nathan Miller from USGS has created his own 3D slab surface model independent of the CFM model.

Author's response: The reviewer raised an important concern. The writing style of the submitted paper may inadvertently suggest that the roughness observed in CASIE21 data are artifacts rather than genuine features. This could potentially give readers the impression that we smoothed the basement surface across different resolutions in an attempt to remove such features. We would like to clarify that this was not our intention. On the contrary, the roughness in the CASIE21 basement surface is real and meaningful.

Before addressing the specific issue, we reiterate that the primary goal of this paper is on presenting a coherent Moho surface—not the basement. Given that the Moho is expected to be smoother than the basement, it is a reasonable and necessary approximation to apply smoothing to the basement to derive a consistent Moho model. This forms the primary motivation for our smoothing approach. Our secondary motivation, as the reviewer correctly pointed out, is to prepare an interface that is more suitable for use in various geophysical modeling and inversion efforts. We also note that researchers interested in the high-resolution CASIE21 basement surface can readily access that dataset directly. It was not the intention of this study to replicate or supplement the CASIE21 basement model, but rather to build upon it for a different set of objectives.

In this paper, we present several combinations of datasets related to slab depth information, along with a simple and easily reproducible workflow implemented in MATLAB. The accompanying code is designed to be accessible, allowing users to modify or update it as needed. The primary aim of this paper is not to assess the accuracy of the Moho interface itself, as definitive conclusions will only be possible once ongoing Moho imaging studies become publicly available. Rather, our objective is to offer a straightforward and structured approach for integrating multiple datasets to construct a coherent Moho interface. This framework can be used and evaluated by researchers in a variety of geophysical applications.

To illustrate these final points we have added a few sentences at the end of the **Introduction** section,

‘The accompanying MATLAB-based workflow is designed to be transparent, accessible, and adaptable, enabling researchers to construct customized slab geometries for diverse geophysical applications. Importantly, the workflow is straightforward to update as new datasets become publicly available, allowing for iterative refinement of the model in support of ongoing community efforts.’

Concern 3

Relationship with ongoing scientific efforts

Lastly, I was surprised to see this publication lead by only two authors, given that the CASIE21 Experiment was a large community experiment funded by NSF and has many people actively working on the data to advance community goals such as the blossoming CRESCENT initiative. Many of the goals that are seemingly resolved in this study (with inferences, not purely data driven) will be filled with data driven publications in the near future.

For example:

- Boston has already conducted a detailed analysis of the CASIE21 Moho reflection and its variations along the Cascadia subduction zone. The manuscript is in prep. Having these results would mitigate having infer the Moho geometry from only the slab top interface and mitigate the issue of deciding how/if to smooth it.

- Canales and his group are analyzing all of the offshore active-source OBS wide angle seismic dataset. They have traveltime tomography models on nearly every dip line, which provide additional constraints on the Moho depth beneath the accretionary prism and shelf region. Not only would these data directly constrain the Moho depth but they also provide seismic velocities to help manage the merge with onshore datasets.
- Carbotte is actively incorporating legacy seismic data from Cascadia to improve constraints on the plate interface. She has compiled a large dataset of legacy reflection data in two-way traveltime and new interpretations on the plate interface. These are then being converted from time to depth by using the 3D seismic velocity model that Nathan Miller has produced. The legacy data provide significant additional constraints, particularly near the shoreline region. A follow up manuscript is in prep. Thus, the updated surface will help improve the geometry near the shoreline and also preserve major segmentation boundaries in the region, such as slab tears that were evident in the Carbotte et al. (2024) study.

All of the abovementioned studies are well underway and have been presented in recent scientific meetings. Thus, I feel that this data report would be significantly improved by encouraging the authors to work collaboratively with other scientists that have already made great progress in this area and would help produce the most reliable subducting plate geometry for our community to use. While it certainly appears that the model presented here is a good starting place, many important updates and additional constraints will be forthcoming. Therefore, at the very least, I think the authors should mention the shortcomings of this model and acknowledge that future updates are underway and be prepared to work with others to release future generations of “CascadiaMoho” i.e. if this is CascadiaMoho1.0, then many CascadiaMohoX.x will be expected in the future as our community efforts converge (or Seismica should consider this aspect if there is a plan/mechanism to incorporate future updates). Since these interfaces are so critical to the community, and a publication like this will attract a lot of attention and the surface would likely be used in real hazard assessments that trickle all the way down to building codes, I think the authors could have made a stronger effort to work with those in the CASIE21 team that are working toward the same goal for the sake of enhancing community-driven science, but should at a minimum reconcile the shortcomings of the technique presented here and acknowledge that future data-driven updates to improve constraints on the Megathrust and Moho geometry are underway.

Author’s response: The authors are well aware of the studies mentioned by the reviewer. We have engaged in discussion with the researchers mentioned in different conferences such as AGU and CRESCENT meetings. Prior to preparing this manuscript, the lead author also contacted Dr. Brandon Schuck, who indicated that the reflection-derived slab structure for offshore Northern California would likely not be available until the end of this year. Based on our communication efforts, we understand that similar timelines apply to other related studies as well.

We do not intend to wait for other studies to conclude before publishing this data report, for several important reasons. There is a pressing need across many ongoing CSZ research efforts for a margin-wide, integrated onshore-offshore Moho structure. This paper directly addresses that need by offering not only a comprehensive Moho interface across the margin but also a straightforward and reproducible workflow for integrating existing datasets. Our goal is to provide the research community with a foundational Moho model that can be iteratively improved, hopefully every year.

In geophysical studies, the initial models used in inversion workflows are often omitted, which can hinder reproducibility. We aim to improve transparency by offering a consistent framework and dataset, including the starting model. This work also contributes to the broader effort of building community velocity models (CVMs) by proposing a Moho interface that can serve as a reliable initial structure within CVM development.

The combined Moho model presented in this paper is already being utilized as a starting point in different geophysical modeling. We are using it in our shore-crossing high-resolution tomographic modeling along the CSZ. In that work, we use PmP phases from the CASIE21 expedition recorded on the Cascadia2021 nodal arrays. This helps us image the Moho in the nearshore region, where both CASIE21 and existing low-resolution onshore models lack reliable slab depth information. Additionally, the combined Moho model is used in the tomographic inversion for building the '0'th version of the CVM for the CSZ (He et al. 2024)*. Through these modeling efforts, we have already identified areas where the combined Moho can be improved. However, it is important to note that these findings have not yet been published. In accordance with the policies of both Seismica and the CRESCENT initiative, unpublished results cannot be included in this study. Our intention is to release a Moho model now, based on already published studies, that provides a consistent and standardized surface for ongoing and future analyses. The outcomes of the ongoing research will be incorporated into a future release, which is why we refer to this version as CascadiaMoho1.0.

*He, B., Herr, B., Delph, J.R., Hooft, E.E., Grant, A., Sahakian, V.J., Share, P.E., Stephenson, W.J., Wirth, E.A., Maguire, R. and Li, G., 2024, December. CRESCENT Generation 0 Cascadia Community Velocity Model: initial constraints from teleseismic receiver functions and ambient noise data. In AGU Fall Meeting Abstracts (Vol. 2024, pp. T43D-03).

To illustrate these points in the manuscript, we have rewritten the last paragraph of the **Results and Future Directions** section.

'This study currently relies on slab depth information only from published onshore and offshore observations. However, these publicly available datasets, when combined, lack direct observations in several key regions. One such gap exists offshore Northern California, where no public slab depth data are available. To address this, we extrapolated an average depth profile from southern Oregon into the northern California margin. Ongoing efforts to reprocess and analyze legacy seismic data in this region (Shuck et al. 2024) are expected to help close this data gap and provide direct observational constraints. Another approximation in this study is the assumption of a uniform 6 km thickness for the oceanic slab. Ongoing works utilizing CASIE21 reflection data aim to measure slab thickness more precisely by directly imaging the oceanic Moho (Boston et al. 2024). These results

will enable future versions of the model to incorporate independently constrained Moho depths, reducing reliance on inferred slab-top information. In addition, PmP arrivals from CASIE21 offshore seismic shots recorded on Cascadia2021 onshore nodal seismometers illuminate the near-shore Moho structure (Ashraf et al. 2024). This region has previously lacked sufficient resolution in both offshore and onshore datasets. Currently, these results are only available for two limited regions in central (Nolan et al. 2022) and south-central Oregon (Ashraf et al. 2025). We anticipate that these ongoing efforts—combining new analyses of legacy data, refined slab thickness measurements, and improved imaging of the nearshore Moho—will significantly enhance the accuracy and continuity of the Moho interface in future versions of this model. These advancements will be integrated into the next iteration of the Cascadia Moho.'