nature portfolio

Peer Review File

Deep subsurface water can sustain giant sequoias

Corresponding Author: Dr Benjamin Eppinger

This file contains all reviewer reports in order by version, followed by all author rebuttals in order by version.

Attachments originally included by the reviewers as part of their assessment can be found at the end of this file.

Version 0:

Reviewer comments:

Reviewer #1

(Remarks to the Author)
Dear Authors,

You present a compelling study of subsurface structures beneath one of California's most iconic and unique forest environments. I find the results novel and creative, particularly in the way high-resolution seismic imaging—specifically full-waveform inversion (FWI)—is used to investigate tree rooting systems. Overall, the manuscript is strong, and I do not have major concerns regarding the methodology or interpretation.

If there is one aspect that could further strengthen the study, it would be additional validation of the rock-physics model used to convert elastic parameters into hydrological and structural properties. For example, in-situ measurements of soil moisture could help validate the inferred shallow volumetric water content. Similarly, shallow soil cores could provide independent constraints on porosity estimates derived from the inversion.

As a non-expert in ecohydrology, I would also like to highlight a potentially complementary mechanism for water acquisition by large trees: moisture capture via condensation and fog interception on tree and plant canopies. This process can be significant in environments characterized by limited summer precipitation and strong diurnal temperature variations, such as many forested regions of California. Condensed water may drip to the ground (fog drip or throughfall), be routed along stems (stemflow), or be directly absorbed by vegetation, thereby contributing to near-surface soil moisture and infiltration within the vadose zone. While this mechanism is unlikely to replace precipitation or snowmelt as a primary water source, it may represent a seasonally important contribution that helps sustain shallow soil moisture and root-zone water availability during dry periods. I suggest acknowledging this process in the discussion section ("Where Do Giant Sequoias Source Their Water From?") as a complementary pathway and a topic for future investigation.

Additional Comments

Is density held fixed during the elastic FWI stage? If so, please clarify how the density model is obtained.

It would be useful to present uncertainty estimates for the inverted rock-physics parameters, at least for key quantities, in the main text.

Please add colorbar labels to Figures 2 and 3.

While precipitation in inches is common in U.S. usage, the manuscript otherwise adopts SI units; for consistency, precipitation could be reported in centimeters.

I look forward to seeing this study published, as it has the potential to motivate a new line of research into subsurface controls on forest dynamics.
Sincerely,

Ettore Biondi

Reviewer #2

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This is a very strong contribution which is publishable. However, its impact would be even stronger is actuial tree-based data were also used and presented to strengthen the conclusion that mostly come from speculation about the amount of water used by the trees [200 m3] and if in fact any real 'stress' would/could be assessed in the trees.

Reviewer #3

(Remarks to the Author)
Dear authors,

This manuscript presents an interesting and timely study that aims to quantify the subsurface distribution of water content beneath giant sequoias in Yosemite National Park. The authors report that giant sequoias may rely on deeper (>2 m) subsurface water stores than previously recognized, based on geophysical imaging and hydrological variable estimation. To support this conclusion, the study applies elastic full-waveform inversion (FWI) to seismic data acquired along hillslope, ridge, and drainage transects, producing P-wave and S-wave velocity models. These velocity models are subsequently used in a geostatistical rock-physics inversion to estimate subsurface porosity and saturation, from which volumetric water content models are derived.

Using the inferred volumetric water content at depth, the authors explore potential rooting depths and lateral rooting extents under a prescribed water-budget model to assess how giant sequoias may survive under increasingly dry climatic conditions. The application of seismic imaging to the critical zone for ecological and hydrological interpretation is novel and well aligned with the journal’s scope. Seismic methods provide a means to infer otherwise inaccessible deep water stores that may sustain large trees. Overall, this manuscript represents an interdisciplinary contribution spanning geophysics, critical zone science, and ecology.
Below are comments and suggestions.

Seismic waveform inversion

The methodological framework for seismic waveform inversion is solid. The choice of a phase-based misfit function for field data is reasonable, as fitting absolute waveforms for field data is often challenging. The synthetic sensitivity tests provide useful insight into the resolving capability of the data and inversion scheme.

That said, inspection of the field-data waveform fits provided in the supplementary figures suggests that some local cycle skipping remains, where synthetic and observed waveforms exhibit clear phase or traveltime mismatches. While achieving a perfect fit with field data is rarely feasible, it would be helpful to further assess inversion quality by providing trace-by-trace residual plots or other quantitative diagnostics across all shot gathers. Such analyses would clarify which portions of the data are not well fit and whether these mismatches are systematic or localized.

The manuscript would also benefit from a discussion of how these waveform misfits may affect the inverted Vp and Vs models, and how uncertainties or errors at the waveform level propagate into the derived velocity structures and, ultimately, into the estimated volumetric water content.

There are also questions regarding data usage across different survey lines. For the hillslope and drainage transects, only the vertical component of the seismic data is used, whereas for other transects both vertical and horizontal components are included. Further clarification is needed on how this difference affects the resulting Vp and Vs models across transects, and how it may influence the interpretation of hillslope, drainage, and ridge environments.

In addition, the treatment of density in the inversion workflow is not clearly described. Density directly affects the conversion from seismic velocities to elastic moduli and therefore influences the subsequent rock-physics and water-content estimates. A clearer explanation of how density is parameterized would strengthen the methodology section.

The initial model construction assumes a constant relationship of Vs = 0.5Vp. Given the strong lithological and mechanical variability expected in the critical zone, where Vp and Vs may vary independently with depth and moisture conditions, further justification for this assumption would be helpful. If surface waves are present in the data, they could potentially be exploited to better constrain the Vs model.

Rock-physics inversion

The rock-physics inversion is the key to link between the seismic velocity models and the inferred porosity, saturation, and volumetric water content. These derived water volumes form the basis for the subsequent water-budget analysis and ecological interpretation..

The unsaturated (dry) rock-physics models are estimated using exponential relationships that rely on several empirical parameters. Additional justification for the selected parameter ranges would be helpful, for example, by relating them to known lithology, soil type, or prior studies in similar environments. Ideally, site-specific constraints or sensitivity analyses could be provided to demonstrate the robustness of the inferred water-content models with respect to these parameter choices.

The rock-physics modeling would also benefit from independent validation. Point measurements (e.g., in situ moisture measurements), if available, could be used to calibrate or validate the rock-physics relationships, with seismic inversion providing spatial extrapolation.

The treatment of density within the rock-physics inversion (i.e., solid density) should be clarified, as density directly enters the formulation linking velocities to porosity and saturation.

Water-budget modeling and ecological interpretation

It would be helpful to clarify whether other potential water sources, such as snowmelt, atmospheric moisture, or internal water storage within the trees, are considered or neglected in the water-budget model. These factors may influence water availability and buffering during dry periods. Discussing their potential impact,and how they may affect uncertainty in the final estimates, would improve the interpretation.

Minor Comments
Figure 2 shows velocity profiles with contour intervals of 1000 m/s for Vp and 500 m/s for Vs, whereas the analysis elsewhere refers to a threshold of ~1200 m/s. It would be helpful to mark this boundary in the figure.

Line 272: Please specify the Gaussian smoothing parameters applied at different frequency bands.

Version 1:

Reviewer comments:

Reviewer #1

(Remarks to the Author)
Dear Authors,

I believe that the updated manuscript has answered all my concerns very well. I think the manuscript can be considered for publication.

Sincerely,

Ettore Biondi

Reviewer #3

(Remarks to the Author)
Dear authors,

I appreciate the efforts that have been put into addressing my comments in the revised manuscript. Those explanations have improved the clarity of this study. After reviewing the response letter and the updated manuscript, I find that my previous comments have been addressed. Thank you again for your responses and efforts.

Best

Review for *Communications in Earth & Environment* / COMMSENV-25-5699-T

Author(s): Eppinger et al.

Title: *Deep Subsurface Water Stores Sustain Giant Sequoias*

General Remarks: This is an excellent contribution to our understanding about the potential subsurface water source use by the Earth's largest tree species. It nicely merges novel geophysical techniques and data with known geological and biological information about the unique distribution of Giant Sequoia (GS) on the granitic dominated substrates it inhabits in the summer-dry mid-elevation forest systems in the southern Sierra Nevada mountains of California USA. The data support the conclusions in a novel way. But because the paper is aimed to directly link subsurface water that is challenging to quantify with the presence of the tree species, it would be helpful, if possible, to have more (or some) actual tree-based or stand-based biological data. Some of the specific comments below address this point. Finally, since the research was only conducted in one of the many giant sequoia groves (>65 others exist) it is important to know the level of confidence the authors have in extrapolating from the single grove they worked in to the other groves (overall range) of the tree species.

Specifics:

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2. Lines 85-87 and Fig. 2; is it possible to look at the actual correlation between the waveform seismic velocity results mapped in Fig, 2 and the stand properties overlying these transect areas (e.g., stand density, age or size structure at these specific locations, crown closure or other metrics of tree health)?
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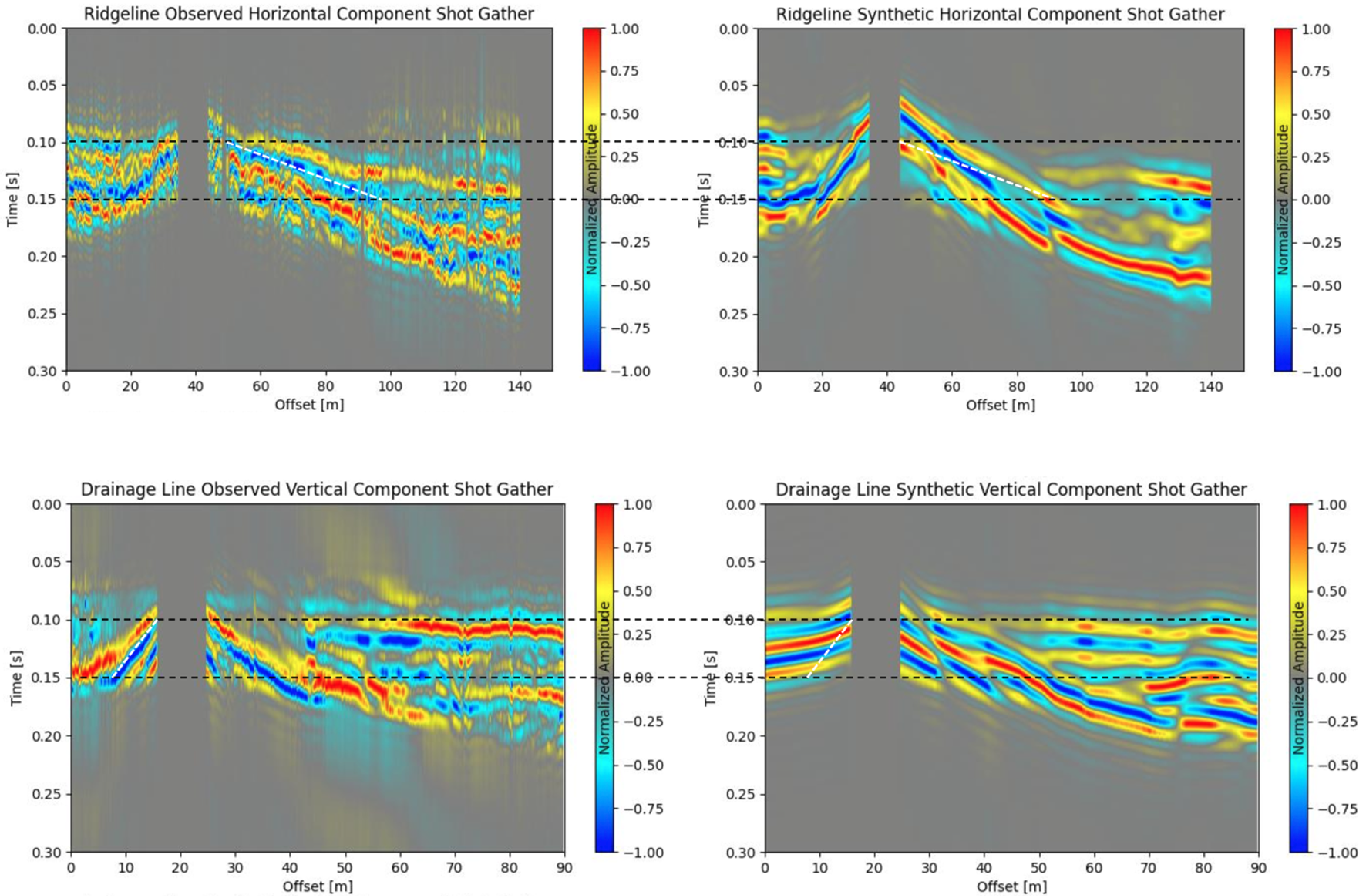
4. Lines 105-115; using moisture release curves of soil water content vs. water potential, can the authors also produce a "water potential" map similar to that for water content shown in Fig. 3? If so, this may allow the plant water potential data collected for this species to me co-mapped or at least a correlation between soil water potential and plant water potential to be explored.
5. Lines 124-132; the authors conjecture about stand properties here and as in comments #2 above, can this be explored more fully?
6. Lines 134-145; is there any chance that stable isotope (H and/or O) data of plant and subsurface water sources were quantified to see how well these correlate with the waveform seismic velocity results shown in the paper? [on lines 141-142

– the comment on the approximate rooting depth cited was based on stable isotope data near the border with Sequoia-Kings National Park].

7. Lines 158-63; the number of each tree using 200 m3 of water in the last part of the dry season “to avoid water stress” seems to be a strong statement / assertion in the absence of data (there are no data shown in the paper on volumetric water use nor what ‘stress’ means in this context since no stress data is presented). While I appreciate the desire to make the link the authors want to make here, in the absence of any tree data on water use and ‘stress’ the assertions presented are speculative at best).
8. Lines 175-191; this section of the paper is in my view the strongest and most novel of the paper that grow directly from the data shown.
9. The novelty of the scientific results shown and the implications for forest management / water resource management is an important contribution of this study and paper. Future studies will clearly benefit from the approach employed. Based on the strength of the results shown this paper should be published. But if additional information on the trees themselves could be added, it would elevate the importance and significance of the paper and research.


Ridgeline Observed Horizontal Component Shot Gather
Ridgeline Synthetic Horizontal Component Shot Gather
Drainage Line Observed Vertical Component Shot Gather
Drainage Line Synthetic Vertical Component Shot Gather
Time [s]
Offset [m]
Normalized Amplitude

REVIEWER COMMENTS:

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Further validation of the rock physics model is a fair ask and would strengthen the certainty of the claims made in the text. To address this concern, we have taken two actions:

1: We have redone the rock physics inversion with new parameters. The parameters are those used by Grana et al. (2026)[1], who calibrated their results with borehole data. More details can be found in the associated work; however, here we note that the calibration data is not from our field site in the Mariposa Grove. Federal regulations make collection of borehole rock samples difficult in the national parks. However, we believe that the calibration data from Grana et al. (2026) is still applicable to our site because the rock type is similar. In Grana et al. (2026) the calibration data were collected from (un)weathered samples of the Sherman granite. In our study, the underlying bedrock is mapped as a metarhyodacite roof pendent (contact metamorphism) with visible grains. Although not identical, both crystalline bedrocks have very low initial porosity and felsic composition. Therefore, we believe the calibration from Grana et al. (2026) is also suitable for this study and the best we can do at this time.

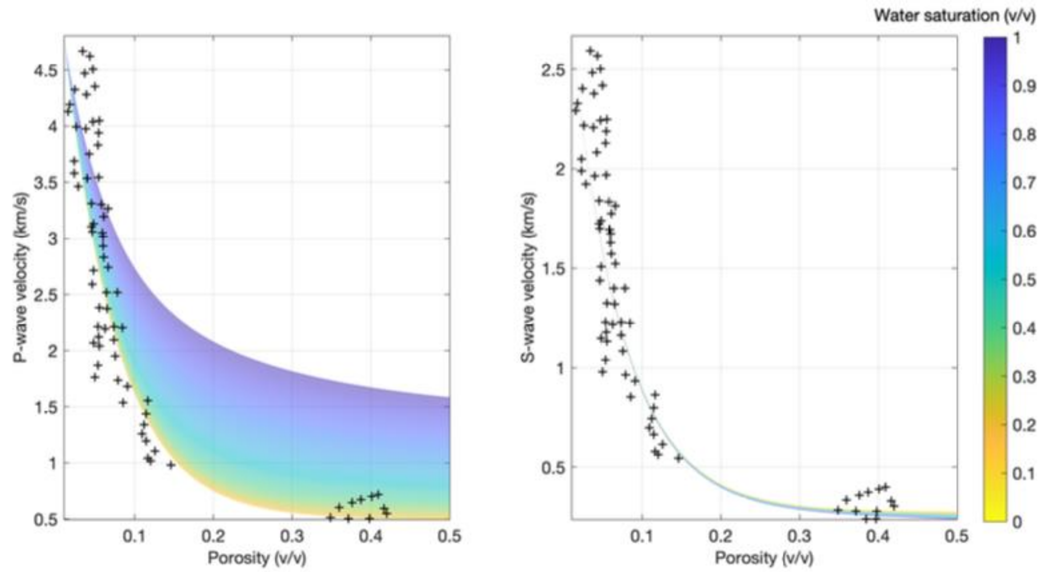

Figure 6: Comparison of elastic rock physics model for partially saturated rocks with measurements of core samples: P- and S-wave velocity versus porosity color coded by water saturation. Black crosses represent the P-wave velocity measurements from the dataset in Flinchum et al. (2018) and computed S-wave velocity values assuming a constant velocity ratio.

*** The figure above is from Grana et al., 2026

We have updated the methods section of the main text to be clearer that we rely on the calibrated rock physics model of Grana et al. (2026). We have also removed the rock physics section from the supplemental material because we are not creating a new rock physics model in this work. We are relying on an already published model. The important argument we make in this work is that the bedrock beneath the Mariposa grove is similar enough to that of the Sherman granite for the rock physics model developed by Grana et al. (2026) to be applicable.

2: Although we cannot go back and collect soil moisture data from when the geophysical data were collected, we did return to the Mariposa Grove in 2025 to collect soil moisture data from areas near the three giant sequoias discussed in the manuscript. While these soil moisture results cannot fully validate the rock physics inversion results, they can confirm the general trend that the models present. These soil moisture results (added in Table 2) show dry soil conditions on the ridge and hillslope near sequoias A and B and wetter conditions in the drainage near sequoia C.

As a non-expert in ecohydrology, I would also like to highlight a potentially complementary mechanism for water acquisition by large trees: moisture capture via condensation and fog interception on tree and plant canopies. This process can be significant in environments characterized by limited summer precipitation and strong diurnal temperature variations, such as many forested regions of California. Condensed water may drip to the ground (fog drip or throughfall), be routed along stems (stemflow), or be directly absorbed by vegetation, thereby contributing to near-surface soil moisture and infiltration within the vadose zone. While this mechanism is unlikely to replace precipitation or snowmelt as a primary water source, it may represent a seasonally important contribution that helps sustain shallow soil moisture and root-zone water availability during dry periods. I suggest acknowledging this process in the discussion section ("Where Do Giant Sequoias Source Their Water From?") as a complementary pathway and a topic for future investigation.

We edited the text to acknowledged foliar uptake (see paragraph two of the section *Where Do Giant Sequoias Source Their Water From?*). Below is more context regarding this matter that we hope the Reviewer will find interesting and helpful.

Response from A. Ambrose:

Complementary water acquisition mechanisms such as direct foliar uptake of condensed water and the contribution of stemflow and fog drip to shallow soil moisture have been shown to be ecologically important in many temperate trees, including coast redwood. However, the ecological importance of these water sources is primarily due to the temporal pattern of their inputs, which can relieve water stress and reduce water demand via reductions in vapor pressure deficit (VPD) during otherwise dry periods (e.g., foliar uptake of fog water and reduced transpiration in coast redwood trees during the summer growing season). However, the total volume of water provided by these other sources and mechanisms is very small compared to the total water use of giant sequoias and does not constitute a significant portion of their total water balance. See Johnstone and Dawson (2010) Climatic context and ecological implications of summer fog decline in the coast redwood region. PNAS 107: 4533-4538[2] for some discussion of this.

Our unpublished sapflow data documents reverse water flow in the upper trunks of giant sequoia trees during periods of rain, snow, and low clouds (similar to fog), establishing that these trees also can directly absorb intercepted or condensed water on their leaves. However, the total volume of water absorbed during these events is miniscule compared to the total water balance of these trees, supporting the conclusion that foliar water uptake in giant sequoia trees can be important for reducing water demand and relieving water stress but does not provide a significant portion of their water supply.

I am not aware of any stemflow or canopy drip data in giant sequoia trees, but my observations over 20+ years of doing field work in giant sequoia forests suggest these are not significant additional sources of water for these trees. Virtually all stemflow gets absorbed by the thick bark on the trunk and evaporates again before reaching the ground. Intercepted water that does not get absorbed by the foliage or bark, or evaporates back into the atmosphere, may drip down to the ground and provide small sporadic inputs that might help to sustain shallow soil moisture during dry periods and may provide some drought relief during otherwise stressful times. But cloud-drip and throughfall are highly unlikely to constitute a major portion of mature giant sequoia tree water budgets. Seedlings and small saplings may benefit more since their total water use is substantially less than mature trees.

Additional Comments

Is density held fixed during the elastic FWI stage? If so, please clarify how the density model is obtained.

In the inversions we parameterize density as a homogeneous field, which is an approach also implemented in several other case studies of near-surface FWI (e.g., Köhn et al., 2018[3]; Wang et al., 2023[4]; Eppinger et al., 2024[5]). The rationale behind this is that density primarily affects amplitude information, but our choice of misfit functional and preprocessing parameters focuses on fitting phase information. We have noted this in the methods section of the main text.

It would be useful to present uncertainty estimates for the inverted rock-physics parameters, at least for key quantities, in the main text.

Please add colorbar labels to Figures 2 and 3.

While precipitation in inches is common in U.S. usage, the manuscript otherwise adopts SI units; for consistency, precipitation could be reported in centimeters.

I look forward to seeing this study published, as it has the potential to motivate a new line of research into subsurface controls on forest dynamics.
Sincerely,

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Reviewer #2 (Remarks to the Author):

This is a very strong contribution which is publishable. However, its impact would be even stronger is actuial tree-based data were also used and presented to strengthen the conclusion that mostly come from speculation about the amount of water used by the trees [200 m3] and if in fact any real 'stress' would/could be assessed in the trees.

A. Ambrose response:

Actual tree-based data were used as the basis for estimating tree water use, not speculation. Using direct trunk sapflow measurements, Ambrose et al. (2016)[6] documented that giant sequoia tree water use can exceed 2 m^3 per day during the late summer, while Williams et al. (2021 Tree Physiology 41: 2262-2278)[7] documents that giant sequoia tree water use can exceed

3.75 m^3 per day. Note that these measurements were made during the late summer but in relatively "normal" hydrological years and do not reflect drought severe conditions. So, the manuscripts' application of 2 m^3 per day seems conservative. And multiplied by 100 days remaining in the dry season seems reasonable.

Our set of papers on giant sequoia tree responses to the 2012-2016 drought presents water potential and other data describing tree water stress and responses. See these papers:

Ambrose et al. 2018. Leaf- and crown-level adjustments help giant sequoias maintain favorable water status during severe drought. *Forest Ecology and Management* 419-420: 257-267.

Stephenson et al. 2018. Patterns and correlates of giant sequoia foliage dieback during California's 2012-2016 hotter drought. *Forest Ecology and Management* 419-420: 268-278.

Nydick et al. 2018. Leaf to landscape responses of giant sequoia to hotter drought: An introduction and synthesis for the special section. *Forest Ecology and Management* 419-420: 249-256.

These papers show that many giant sequoia trees were experiencing unusual levels of water stress during this drought and exhibited both leaf- and crown-level responses to avoid severe hydraulic damage. The magnitude of these responses varied across the landscape, which could partially be explained by local site characteristics, including variables related to site water balance (e.g., wet meadow sites versus dry ridgetop sites).

The submitted manuscript is consistent with the patterns and mechanisms described in these papers.

Review for Communications in Earth & Environment / COMMSENV-25-5699-T Author(s): Eppinger et al.
Title: Deep Subsurface Water Stores Sustain Giant Sequoias
General Remarks: This is an excellent contribution to our understanding about the potential subsurface water source use by the Earth's largest tree species. It nicely merges novel geophysical techniques and data with known geological and biological information about the unique distribution of Giant Sequoia (GS) on the granitic dominated substrates it inhabits in the summer-dry mid-elevation forest systems in the southern Sierra Nevada mountains of California USA. The data support the conclusions in a novel way. But because the paper is aimed to directly link subsurface water that is challenging to quantify with the presence of the tree species, it would be helpful, if possible, to have more (or some) actual tree-based or stand-based biological data. Some of the specific comments below address this point. Finally, since the research was only conducted in one of the many giant sequoia groves (>65 others exist) it is important to know the level of confidence the authors have in extrapolating from the single grove they worked in to the other groves (overall range) of the tree species.

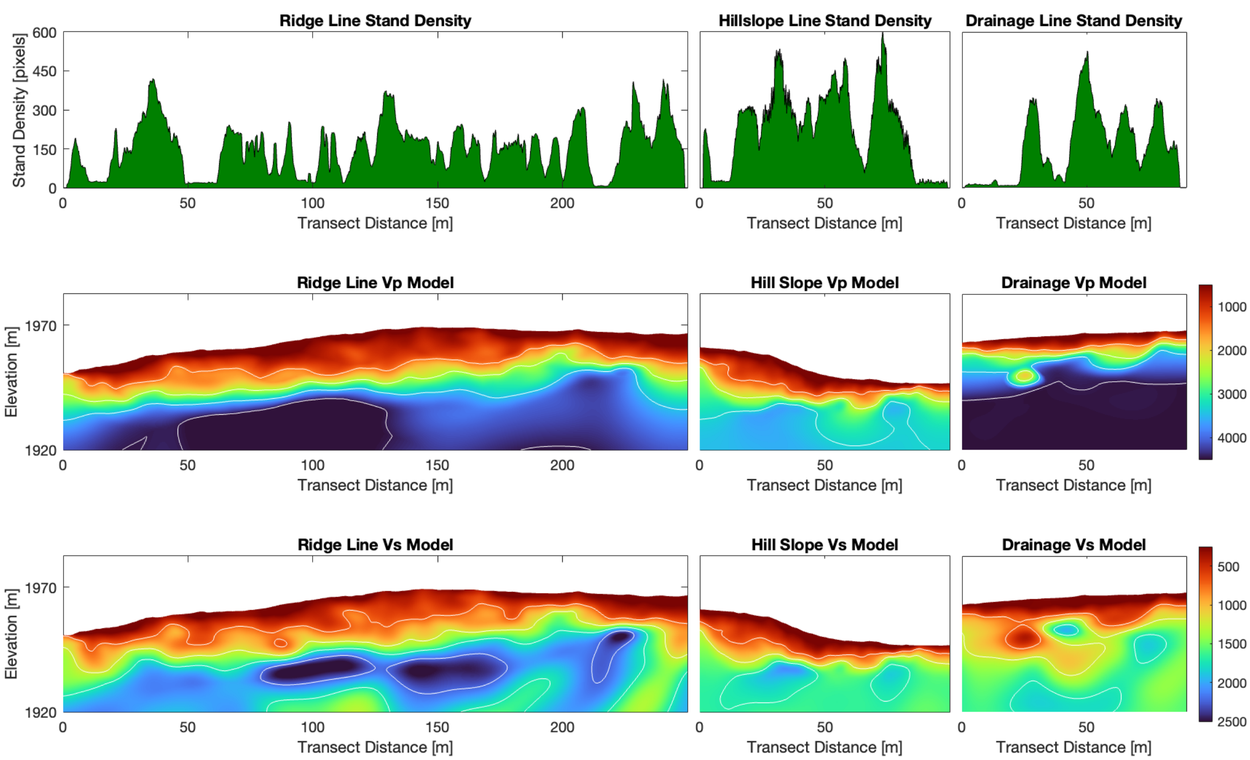
Specifics:

1. Knowing that giant sequoias exists in relatively small and well circumscribed groves makes me wonder if the findings for the Mariposa Grove is generalizable across these other groves? Can the authors conjecture about this based on their knowledge of the mapped geology of the subsurface where the other groves occur?'

The question the reviewer II asks here is pertinent and we try to address it with the second-to-last paragraph of main text. We have revised this paragraph to make it clearer that the other research cited not only corroborates our findings in the Mariposa grove but also implies that giant sequoias in other groves may also rely on deep subsurface water stores.

2. Lines85-87 and Fig.2; is it possible to look at the actual correlation between the waveform seismic velocity results mapped in Fig, 2 and the stand properties overlying these transect areas (e.g., stand density, age or size structure at these specific locations, crown closure or other metrics of tree health)?

Using the combined handheld and ariel lidar products (lidar silhouettes of vegetation shown in Figures 2 and 3), we can quantity stand density along the geophysics profiles. We quantify stand density as a function of transect distance by summing together all the pixels that record a lidar return at each x-location along the transect. Below we show these stand density plots along with the FWI models so that the two can be compared like reviewer II asks. We have included these stand density plots in the extended data of the main text.



3. How far from the transect lines can the results apply (e.g.,the width of the data acquired reaches out how far?)?

The geophysical data we collected and processed using three linear profiles of sources and receivers (see Figure 1). No out-of-plane data was used or processed. The extent to which the results can be applied away from the transect depends on the subsurface heterogeneity.

4. Lines105-115; using moisture release curves of soil water content vs. m water potential, can the authors also produce a "water potential" map similar to that for water content shown in Fig. 3? If so, this may allow the plant water potential data collected for this species to be co-mapped or at least a correlation between soil water potential and plant water potential to be explored.

While this a cogent suggestion, it is complicated to implement due to the mixture of materials within the purview of the water content model. These materials include soil, saprolite, and weathered bedrock, all of which would require different water release curves. While water retentions curves are available for a wide variety of soils, they are far less common for saprolite and weathered bedrock. However, it is worthwhile noting that large particles decrease the magnitude of negative water potential at low soil moisture [8]. We have added a note about this in the second-to-last paragraph of the main text.

4. Lines124-132; the authors conjecture about stand properties here and as in comments #2 above, can this be explored more fully?

We have edited this text to now reference explicitly the stand density plot (see response to comment #2) This explores the argument in a quantitively manner.

6. Lines134-145; is there any chance that stable isotope(H and/or O)data of plant and subsurface water sources were quantified to see how well these correlate with the waveform seismic velocity results shown in the paper? [on lines 141-142]

The isotope data were collected a different locations from the seismic data, so we cannot correlate the two directly at this time. We can only point to the fact the both data sets independently point to the same conclusion.

– the comment on the approximate rooting depth cited was based on stable isotope data near the border with Sequoia-Kings National Park].

7. Lines 158-63; the number of each tree using 200m3 of water in the last part of the dry season "to avoid water stress" seems to be a strong statement / assertion in the absence of data (there are no data shown in the paper on volumetric water use nor what 'stress' means in this context since no stress data is presented). While I appreciate the desire to make the link the authors want to make here, in the absence of any tree data on water use and 'stress' the assertions presented are speculative at best).

Thank you for this criticism, we do not intend to speculate and have added some caveats to this 200 m^3 figure. Please find the revised text below.

"Therefore, each giant sequoia tree would require up to ~200 m^3 of subsurface water if the daily water-usage estimate of 2m^3/day[6] is extrapolated to the end of October. However, there are several factors that could diminish the volume of subsurface water required, including soil moisture recharge via precipitation, foliar uptake, and sequoias adapting their water use as subsurface stores are depleted. Between July and October of both 2023 and 2024 the Mariposa Grove received less than 2.5 cm of precipitation [9,10], and unlike their cousins, the coast redwoods (Sequoia sempervirens)[2], there are no data showing that foliar uptake is a significant source of water for giant sequoias. At this time, it is unclear precisely how giant sequoias adapt their water use throughout the dry seasons, but this question can be tackled by future research using giant sequoia sap flow data."

8. Lines175-191; this section of the paper is in my view the strongest and most novel of the paper that grow directly from the data shown.

9. The novelty of the scientific results shown and the implications for forest management / water resource management is an important contribution of this study and paper. Future studies will clearly benefit from the approach employed. Based on the strength of the results shown this paper should be published. But if additional information on the trees themselves could be added, it would elevate the importance and significance of the paper and research.

Reviewer #3 (Remarks to the Author):

Dear authors,

This manuscript presents an interesting and timely study that aims to quantify the subsurface distribution of water content beneath giant sequoias in Yosemite National Park. The authors report that giant sequoias may rely on deeper (>2 m) subsurface water stores than previously recognized, based on geophysical imaging and hydrological variable estimation. To support this conclusion, the study applies elastic full-waveform inversion (FWI) to seismic data acquired along hillslope, ridge, and drainage transects, producing P-wave and S-wave velocity models. These velocity models are subsequently used in a geostatistical rock-physics inversion to estimate subsurface porosity and saturation, from which volumetric water content models are derived.

Using the inferred volumetric water content at depth, the authors explore potential rooting depths and lateral rooting extents under a prescribed water-budget model to assess how giant sequoias may survive under increasingly dry climatic conditions. The application of seismic imaging to the critical zone for ecological and hydrological interpretation is novel and well aligned with the journal's scope. Seismic methods provide a means to infer otherwise inaccessible deep water stores that may sustain large trees. Overall, this manuscript represents an interdisciplinary contribution spanning geophysics, critical zone science, and ecology. Below are comments and suggestions.

Seismic waveform inversion

The methodological framework for seismic waveform inversion is solid. The choice of a phase-based misfit function for field data is reasonable, as fitting absolute waveforms for field data is often challenging. The synthetic sensitivity tests provide useful insight into the resolving capability of the data and inversion scheme.

That said, inspection of the field-data waveform fits provided in the supplementary figures suggests that some local cycle skipping remains, where synthetic and observed waveforms exhibit clear phase or traveltime mismatches. While achieving a perfect fit with field data is rarely feasible, it would be helpful to further assess inversion quality by providing trace-by-trace residual plots or other quantitative diagnostics across all shot gathers. Such analyses would clarify which portions of the data are not well fit and whether these mismatches are systematic or localized.

We were deeply concerned about the cycle skipping pointed out by the reviewer. We want to show and publish only quality FWI models and be as transparent as possible about how well the models fit the data and the limitations of said models.

In response to this comment, we have redone the FWI results. We used a different misfit functional corresponding to localized wave equation travel time tomography (Hu et al., 2020[11], Wang et al., 2019[12], Huang et al., 2023[13]). This misfit function is similar to the time-frequency phase misfit function we previously used in that it primarily matches phase information. However, we have opted to use localized wave equation travel time tomography because it was been applied several times to implement FWI on real-world exploration data (Wang et al., 2019[12], Huang et al., 2023[13]).

In the supplementary information, we show updated shot gathers. In the additional data we include trace-by trace comparisons for all shot gathers.

We also include summary histograms of the measured time lags between observed and synthetic data across all windows, traces, and shots at each line. Narrowing of the time lag distributions shows the extent to which the FWI has decreased the time lags.

The manuscript would also benefit from a discussion of how these waveform misfits may affect the inverted Vp and Vs models, and how uncertainties or errors at the waveform level propagate into the derived velocity structures and, ultimately, into the estimated volumetric water content.

As with any study involving numerical modeling and fitting noisy real-world data, there are bound to be imperfections in the models. That is why it is encouraging that other independent lines of evidence also suggest that giant sequoias may access and utilize deep subsurface water stores. These additional lines of evidence are noted in the second to last paragraph of the main text. We have revised this paragraph to both acknowledge the uncertainties in our results and also emphasize that the claims we make are corroborated by other studies.

There are also questions regarding data usage across different survey lines. For the hillslope and drainage transects, only the vertical component of the seismic data is used, whereas for other transects both vertical and horizontal components are included. Further clarification is needed on how this difference affects the resulting Vp and Vs models across transects, and how it may influence the interpretation of hillslope, drainage, and ridge environments.

There is ultimately more uncertainty in hill slope and drainage models because horizontal component data were not collected on these lines. However, synthetic tests and FWI applied to field data from Liu et al. (2022)[14] have shown that shear wave velocity models and VP:VS ratios can be recovered from the inversion vertical component body waves.

In addition, the treatment of density in the inversion workflow is not clearly described. Density directly affects the conversion from seismic velocities to elastic moduli and therefore influences the subsequent rock-physics and water-content estimates. A clearer explanation of how density is parameterized would strengthen the methodology section.

In the inversions we parameterize density as a homogeneous field, which is an approach also implemented in several other case studies of near-surface FWI (e.g., Köhn et al., 2018[3]; Wang et al., 2023[4]; Eppinger et al., 2024[5]). The rationale behind this is that density primarily affects amplitude information, but our choice of misfit functional and preprocessing parameters focus on fitting phase information. We have noted this in the methods section of the main text.

The density values used in the FWI do not affect the rock physics inversion because the rock physics model is empirically calibrated to velocity not density (see Grana et al., (2026)).

The initial model construction assumes a constant relationship of Vs = 0.5Vp. Given the strong lithological and mechanical variability expected in the critical zone, where Vp and Vs may vary independently with depth and moisture conditions, further justification for this assumption would be helpful. If surface waves are present in the data, they could potentially be exploited to better constrain the Vs model.

This is an insightful remark that using the same initial VP:VS ratio across the lines may not be advantageous. After more testing, we found that while an initial VP:VS ratio 2.0 worked well for the ridge and hillslope lines, the inversion results for the drainage line converged better when using an initial VP:VS of 3.0. This is likely due to the wetter conditions in the drainage.

Our slope and offset muting parameters are designed to use surface waves near the source. At further offsets, the surface waves may scatter or become incoherent. Therefore, we focus on inverting the body waves at further offsets.

Rock-physics inversion

The rock-physics inversion is the key to link between the seismic velocity models and the inferred porosity, saturation, and volumetric water content. These derived water volumes form the basis for the subsequent water-budget analysis and ecological interpretation.

The unsaturated (dry) rock-physics models are estimated using exponential relationships that rely on several empirical parameters. Additional justification for the selected parameter ranges would be helpful, for example, by relating them to known lithology, soil type, or prior studies in similar environments. Ideally, site-specific constraints or sensitivity analyses could be provided to demonstrate the robustness of the inferred water-content models with respect to these parameter choices.

Reviewer I posed a similar concern. We have copied the relevant part of the response below for the convenience of reviewer III. We believe that this addresses the concern posed here by reviewer III.

We have redone the rock physics inversion with new parameters. The parameters are those used by Grana et al. (2026)[1], who calibrated their results with bore hole data. More details can be found in the associated work, however here we note that the calibration data is not from our field site in the Mariposa Grove. Federal regulations make collection of borehole rock samples difficult in the national parks. However, we believe that the calibration data from Grana et al., (2026) is still applicable to our site because the rock type is similar. In Grana et al. (2026) the calibration data were collected from (un)weathered samples of the Sherman granite. In our study, the underlying bedrock is mapped as a metarhyodacite roof pendent (contact metamorphism) with visible grains. Although not identical, both crystalline bedrocks have very low initial porosity and felsic composition. Therefore, we believe the calibration from Grana et al. (2026) is also suitable for this study and the best we can do at this time.

The rock-physics modeling would also benefit from independent validation. Point measurements (e.g., in situ moisture measurements), if available, could be used to calibrate or validate the rock-physics relationships, with seismic inversion providing spatial extrapolation.

Again, we note that Reviewer I posed a similar concern and have copied the relevant part of the response below for the convenience of Reviewer III.

Although we cannot go back and collect soil moisture data from when the geophysical data were collected, we did return to the mariposa grove to collect in the summer of 2025 to collect soil moisture data from near the three giant sequoias discussed in the manuscript. While these soil moisture results cannot validate the rock physics inversion results, they can confirm the general trend that the models present. These soil moisture results added in Table 2 show dry soil conditions on the ridge and hillslope near sequoias A and B and wetter conditions in the drainage near sequoia C.

The treatment of density within the rock-physics inversion (i.e., solid density) should be clarified, as density directly enters the formulation linking velocities to porosity and saturation.

The density values used in the seismic wavefield modeling do not affect the rock physics inversion because the rock physics model is empirically calibrated to velocity not density. The density parameters used in the rock physics inversion correspond to the densities of mineral, water, and air phases and are given in Grana et al. (2026).

Water-budget modeling and ecological interpretation

It would be helpful to clarify whether other potential water sources, such as snowmelt, atmospheric moisture, or internal water storage within the trees, are considered or neglected in the water-budget model. These factors may influence water availability and buffering during dry periods. Discussing their potential impact,and how they may affect uncertainty in the final estimates, would improve the interpretation.

Anthony Comment

I have addressed some of these points in the response to Reviewer #1 above. Here's a few more responses:

Snowmelt is a critical source of water for giant sequoia ecosystems and supplies the majority of water inputs to these groves. But this is not an "other potential water source" since the soil moisture estimates in the manuscript and in our independent measurements incorporate this water source. I'm not sure what the reviewer means by this.

Williams et al. (2017, *Tree Physiology* 37: 1312-1326) and Williams et al. (2021, cited above) examined water storage and hydraulic capacitance in giant sequoias. Here's a conclusion from the 2021 paper:

"Large *Sequoiadendron* trees contain expansive sapwood cross-sectional areas, wide tracheids, and abundant foliage that in combination can support water budgets exceeding 3000 L day^{-1}. The relatively small water storage capacities and hydraulic capacitances we observed among tree-top stems may be associated with chronically low water potentials imposed by gravity, which we hypothesize are caused by a trend of decreasing water storage dynamics with height in tree. Nonetheless, we estimate that on typical summer days elastic water storage at the tops of large *Sequoiadendron* trees contributes ~9% of daily transpiration, with <2% of that stored water derived from stems (present study) and 7% from foliage (Williams et al. 2017)."

So, like foliar uptake, water storage and capacitance in giant sequoias is probably important for buffering tree water stress and can reduce demand on soil moisture supplies but does not constitute a substantial portion of tree water budgets at seasonal or annual time scales and does not substantially alter the conclusions of the manuscript.

Minor Comments

Figure 2 shows velocity profiles with contour intervals of 1000 m/s for Vp and 500 m/s for Vs, whereas the analysis elsewhere refers to a threshold of ~1200 m/s. It would be helpful to mark this boundary in the figure.

Line 272: Please specify the Gaussian smoothing parameters applied at different frequency bands.

References

1. Grana, D. *et al.* A rock physics model for geophysical inversion in critical zone studies.
2. Johnstone, J. A. & Dawson, T. E. Climatic context and ecological implications of summer fog decline in the coast redwood region. *Proc. Natl. Acad. Sci. U.S.A.* **107**, 4533–4538 (2010).
3. Köhn, D. *et al.* Comparison of time-domain SH waveform inversion strategies based on sequential low and bandpass filtered data for improved resolution in near-surface prospecting. *Journal of Applied Geophysics* **160**, 69–83 (2019).
4. Wang, Y., Khorrami, M., Tran, K. T. & Horhota, D. Application of ambient noise tomography for deep void detection. *Journal of Applied Geophysics* **209**, 104922 (2023).
5. Eppinger, B. J., Holbrook, W. S., Liu, Z., Flinchum, B. A. & Tromp, J. 2D Near-Surface Full-Waveform Tomography Reveals Bedrock Controls on Critical Zone Architecture. *Earth and Space Science* **11**, e2023EA003248 (2024).
6. Ambrose, A. R. *et al.* Hydraulic constraints modify optimal photosynthetic profiles in giant sequoia trees. (2016).

7. Williams, C. B., Koch, G. W. & Dawson, T. E. The dynamics of stem water storage in the tops of Earth's largest trees—Sequoiadendron giganteum. **41**, (2021).

8. Gubiani, P. I. *et al.* Rock size fragments reduction allow including their effect on water retention properties determined with a dew point potentiometer. *Revista Brasileira de Ciência do Solo* **45**, e0200182 (2021).

9. Monthly Precipitation Summary Water Year 2023. California Nevada River Forecast Center (2023).

10. Monthly Precipitation Summary Water Year 2024. California Nevada River Forecast Center (2024).

11. Hu, Y., Han, L. G., Liu, Y. S. & Jin, Z. Y. Wave Equation-Based Local Traveltime Inversion. *Earth and Space Science* **7**, e2020EA001193 (2020).

12. Wang, P., Zhang, Z., Mei, J., Lin, F. & Huang, R. Full-waveform inversion for salt: A coming of age. *The Leading Edge* **38**, 204–213 (2019).

13. Huang, Y. *et al.* Toward high-fidelity imaging: Dynamic matching FWI and its applications. *The Leading Edge* **42**, 124–132 (2023).

14. Liu, X., Zhu, T. & Hayes, J. Critical Zone Structure by Elastic Full Waveform Inversion of Seismic Refractions in a Sandstone Catchment, Central Pennsylvania, USA. *JGR Solid Earth* **127**, e2021JB023321 (2022).

Reviewers' comments:

Reviewer #1 (Remarks to the Author):

Dear Authors,

I believe that the updated manuscript has answered all my concerns very well. I think the manuscript can be considered for publication.

Sincerely,

Ettore Biondi

We are happy and appreciate that Reviewer #1 feels that we have addressed all of their concerns.

Reviewer #3 (Remarks to the Author):

Dear authors,

I appreciate the efforts that have been put into addressing my comments in the revised manuscript. Those explanations have improved the clarity of this study. After reviewing the response letter and the updated manuscript, I find that my previous comments have been addressed. Thank you again for your responses and efforts.

Best

We are happy and appreciate that Reviewer #3 feels that we have addressed all their concerns.

We did not receive a second set of comments from Reviewer #2.