Nonlinear Wavefield Characteristics of Seismic Translation and Rotation in Small-Strain Deformation: Insights from Moment Tensor Simulations

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Replies to Reviewer Comments

We extend our heartfelt gratitude for the reviewer's review and invaluable suggestions, which have enhanced the quality of our manuscript. We have thoroughly addressed each of the reviewer's comments and revised the manuscript accordingly. Below is a detailed account of our revisions and responses to the reviewer's feedback.

1. Revisions to Equations and Mathematical Notation

Response: Thank you for the comments. We have systematically revised the equations throughout the manuscript. Specifically, we removed the symbol θ from Eq. (9) and replaced it with standard tensor indices i,j,k, ensuring consistency with definitions in the text. For the velocity-stress equations (now Eq. (11)), we clarified the physical meaning of the time step *dt* and explicitly described its role in the discretization process (please see Lines 147-149).

Additionally, nonlinear terms in the equations are now highlighted using underlines and annotations to improve readability in the revised manuscript.

2. Code Validation and Benchmarking

Response: Thank you for the comments. We have replaced the original 2D staggered-grid schematic with a 3D diagram to clearly illustrate the spatial distribution of variables within the computational grid (please see Fig. 2). Following the recommendation, we conducted benchmark tests using the SPICE code framework. By comparing numerical results with reference solutions in homogeneous media models, the quantified waveform misfit errors, with detailed validation procedures and outcomes documented in the attached Accuracy Report, please find them attached.

3. Optimization of Results Presentation

Response: Thank you for the comments. In the "Forward modeling parameters" section, we added explicit criteria for selecting points per wavelength and the Courant number, ensuring numerical stability (Please see Lines 196-203). The single waveforms have been converted from the XYZ coordinate system to the RTZ system to align with observational seismology practices. We have streamlined lengthy qualitative descriptions and introduced quantitative comparisons, such as wavefield differences; please see the revised manuscript.

4. Limitations of Data Comparisons

Response: Thank you for the comments. In the revised "Discussion" section, we explicitly outline the current model's limitations, including the omission of attenuation, anisotropy, and small-scale heterogeneities. We further delineate future directions to address these constraints, such as incorporating viscoelasticity and complex media models; please see the revised manuscript.

5. Restructuring and Phased Research Recommendations

Response: Thank you for the comments. We fully understand the rationality of publishing the research in stages and have revised the manuscript. The revised manuscript focuses on the theoretical construction of nonlinear seismic wave propagation and the simulation and analysis of earthquake source mechanisms.

The comparison of observational data in the original manuscript has been deleted to ensure the focus of the topic, and we have included the nonlinear study of observational data as a possible independent and more in-depth and targeted research content in the future.

Regarding the computational code utilized in this study, we wish to clarify that the current manuscript does not prioritize code publication, as the codebase has not yet reached the standards required for public release. We are systematically refining the code architecture—including enhancing scalability features such as parallelization and viscoelastic attenuation modules—to ensure robustness and reproducibility. The present work focuses on theoretical advancements in nonlinear seismic wave propagation, while code dissemination and data-driven validation will be addressed in subsequent phases of this research program. We sincerely appreciate the reviewer's suggestions on improving the code ecosystem and will integrate these insights into our ongoing development efforts.

We deeply appreciate the reviewer's feedback on our manuscript and the guidance on code validation for elevating the rigor and clarity of this work. All revisions are highlighted in the revised manuscript, and please find the attached sumplement materials about the benchmark.

List of major changes in the revised manuscript

1. Rewritten the abstract and title.

2. Theory and method

Revised the equations, ensured that consistent notation rules and symbols were used in all equations, and simplified the presentation of lengthy tensor formulas. (Pages 6 - 9)

3. Simulations of basic seismic moment sources

1) Added quantitative analyses (Figs. 4, 6, 8) of the three source simulations and rewritten the analyses to remove unnecessarily lengthy qualitative analyses and to focus on the linkages to the force source mechanisms and quantitative analyses. (Pages 12 - 18)

2) Modified Fig.6 (now Fig. 9), with the addition of a sensitivity comparison of rotational and translational components, rewritten the analysis of the simulation results (with added Table 1), and deleted the comparison results over time. (Pages 19 - 20)

4. Observations and simulations of two earthquakes

Deleted the presentation of measured data irrelevant to this study objective, focusing on modeling and analyzing source-related nonlinear effects recorded by ground motions of the two earthquakes, and rewritten the analysis content. **(Pages 21 - 25)**

5. Discussion and conclusion

Based on the modified above analysis content, we have rewritten the conclusion and the discussion sections. (Pages 26 - 28)