Evaluating Earthquake Location Methods Using a Synthetic Earth Model and Ridgecrest Earthquakes

Stanford | Doerr
School of Sustainability
Geophysics

Yifan Yu; William L. Ellsworth; Gregory C. Beroza
Stanford University, Stanford, CA
Contact: Yifan Yu (yuyifan@stanford.edu)

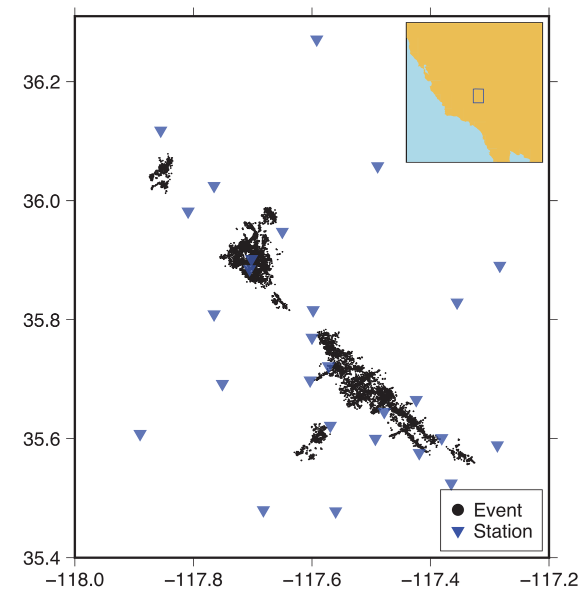
SCEC
AN NSF+USGS CENTER

Introduction

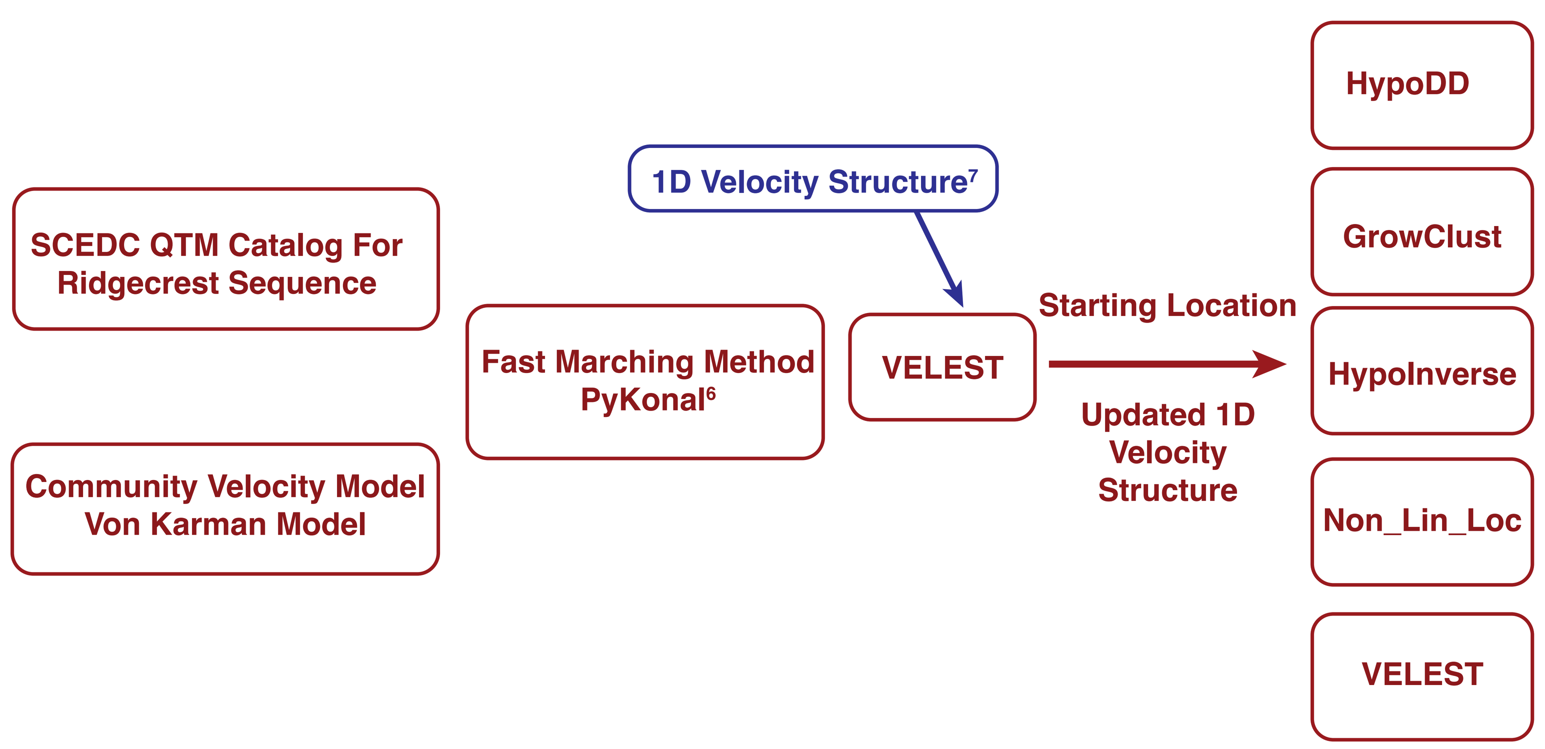
- **This study investigates earthquake location methods to address the differences raised from different approaches.**
- **Two relative location (HypoDD[1], Growclust[2]) and three absolute location (VELEST[3], HypoInverse[4], Non_lin_Loc[5]) methods are compared on a synthetic dataset.**
- **Our results indicate that joint location methods (HypoDD & Growclust) effectively recover relative structures but exhibit distinct performance on resolving depth.**

To build a synthetic traveltime dataset:

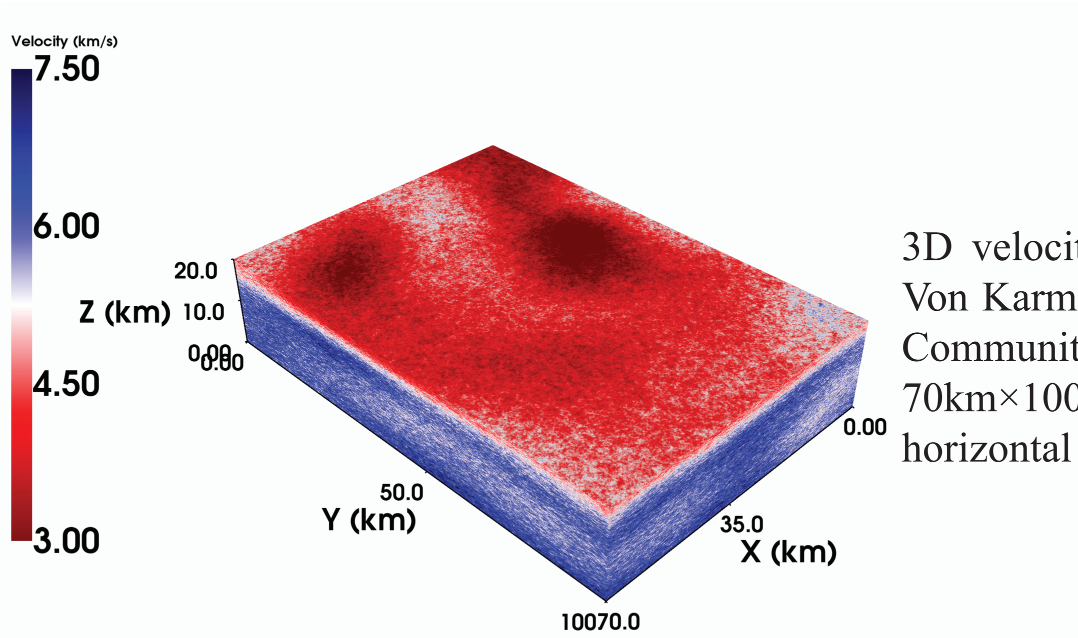
- Sources are randomly drawn from the SCEDC QTM Catalog
- All SCEDC available stations in the region are used
- 3D community velocity model + Von Karman model
- Eikonal based Fast Marching Method traveltime calculator



Method

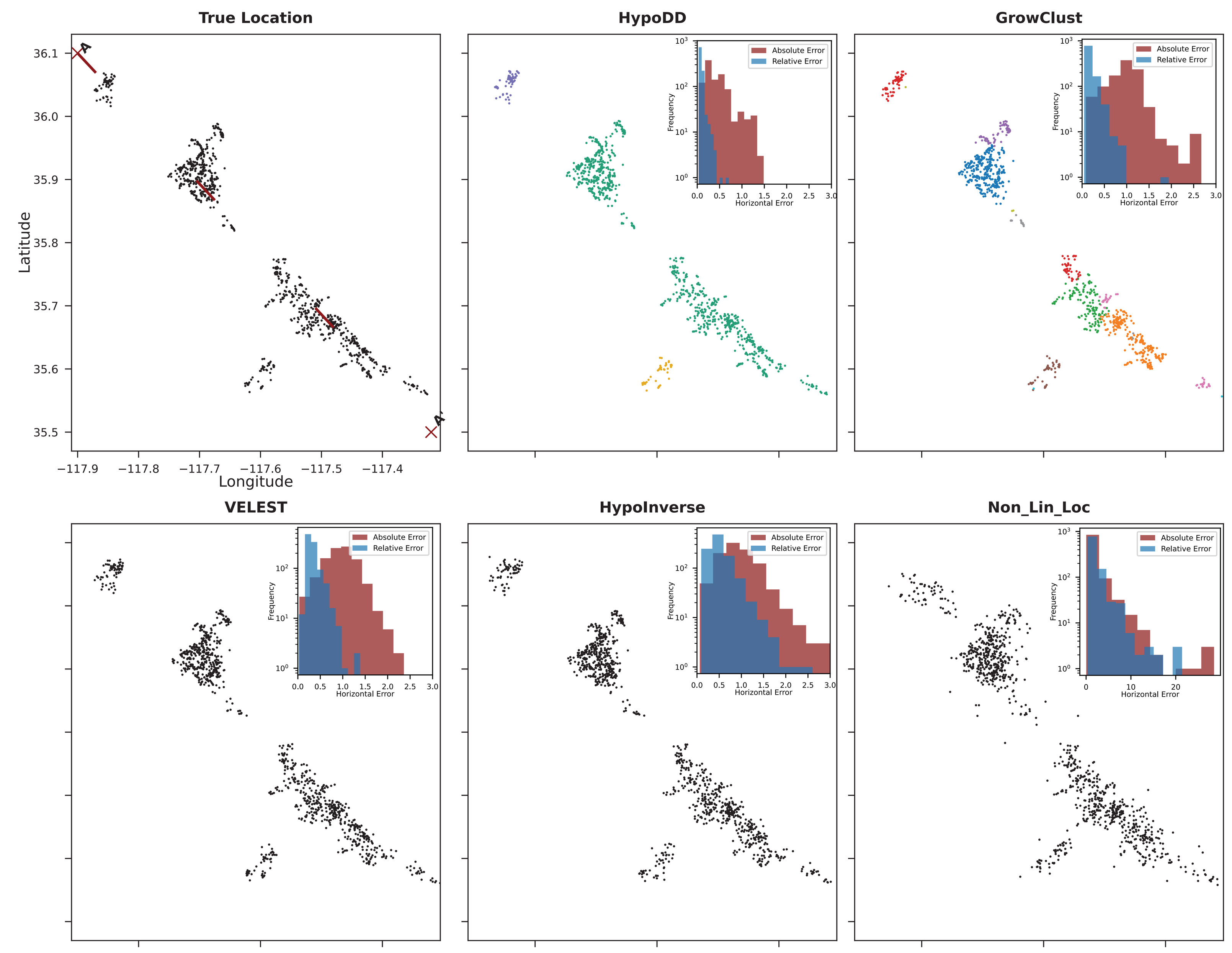


1000 sources are randomly drawn from the catalog. Traveltimes are computed by the Fast Marching Method (PyKonal) in a 3D velocity model, plus realistic Laplacian distribution errors. We generate events' P phase pick availability on each station with 0.67 probability and S phase of 0.5 probability.

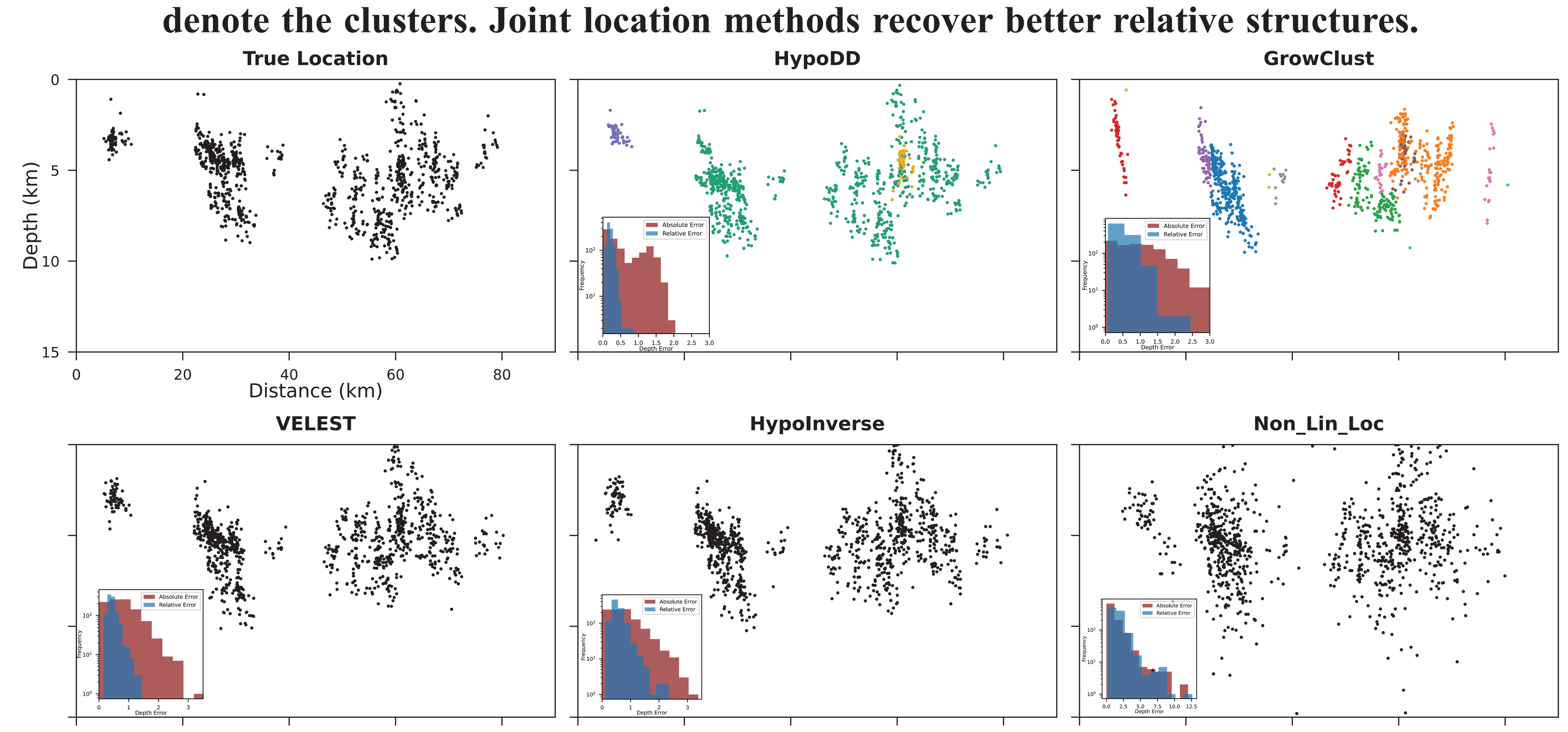


3D velocity model is constructed by adding Von Karman perturbation model to the SCEC Community Velocity model. The scale is 70km×100km×20km, with grid size 100m in horizontal direction and 50m in depth.

Results



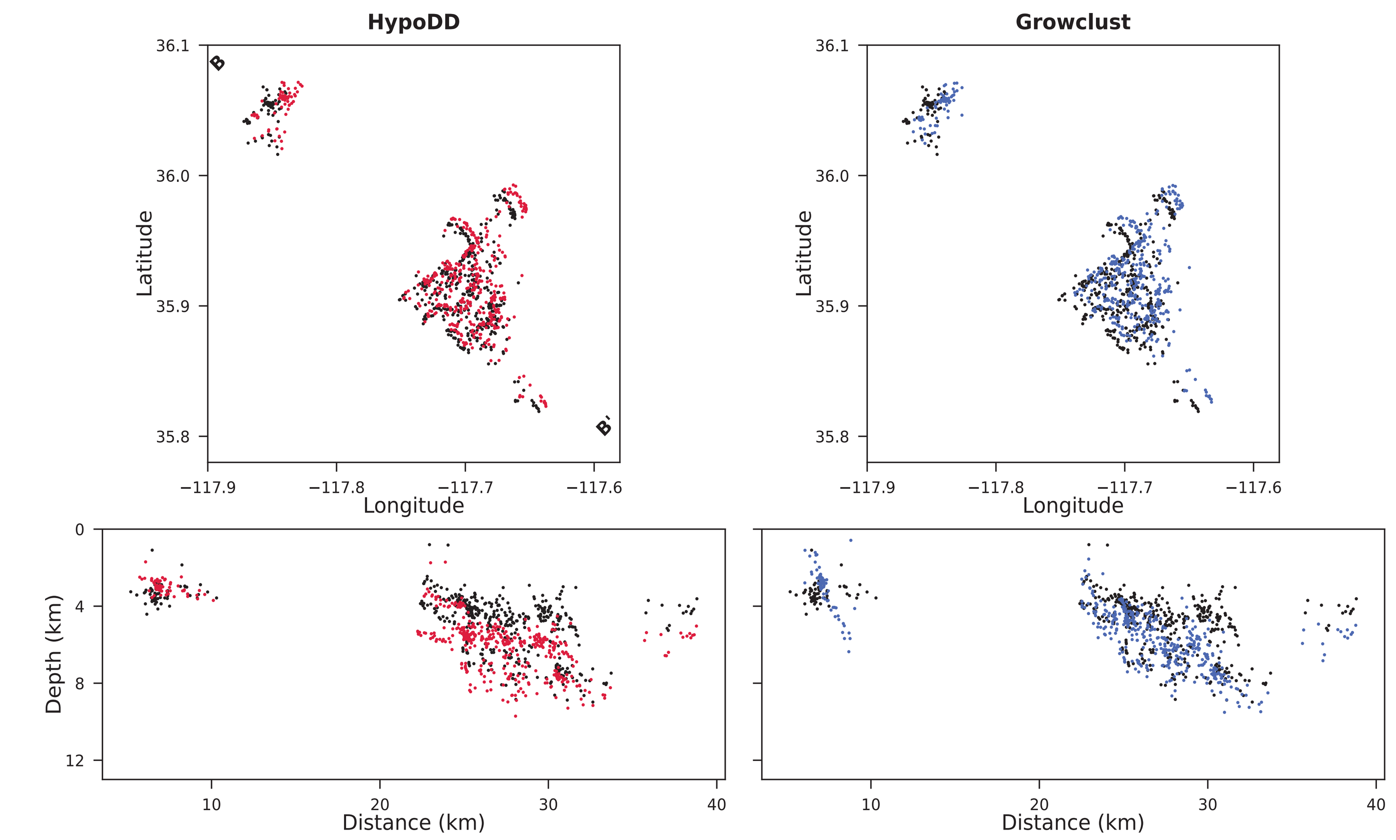
The mapview of true locations and all preliminiray results, with histograms of relative and absolute errors in corners. The colors in HypoDD and Growclust denote the clusters. Joint location methods recover better relative structures.



The depth profile along A-A'. Two joint location methods exhibit different results: while HypoDD preserves most of the structure, clusters tend to form lineations in Growclust.

Method	Mean Absolute Error (km)		Mean Relative Error (km)		Execution
	Horizontal	Depth	Horizontal	Depth	Time (s)
VELEST	0.952	0.788	0.338	0.461	60
HypoDD	0.414	0.645	0.090	0.209	17
Growclust	0.959	0.974	0.194	0.529	6
HypoInverse	0.940	0.770	0.519	0.568	2
Non_Lin_Loc	2.100	1.238	2.056	1.746	380

Performance of five algorithms.



The comparison of two relative location methods in the northwestern part of the region. (Black: real location, Red: HypoDD, Blue: Growclust) While both results slightly shift the structure in a mapview, they are different on constraining the depths.

Summary & Discussion

We conducted a comparative analysis of five location methods using the synthetic traveltime data generated through the Fast Marching Method within a 3D velocity structure derived from the Ridgecrest earthquake sequence scenario. Our findings show that employing joint locating strategies leads to superior results in capturing relative structural information. While both HypoDD and Growclust exhibit similar accuracy in recovering horizontal relative structures, they diverge in ability to solve the accurate depth distributions. These disparities likely arise from the distinctive approaches employed by these two algorithms, including their use of norms and update strategies.

Try Locate Yourself!

As hyperparameters vary and function diversely among methods, each program may not be at its peak in our test

Feel free to test any location algorithm on our dataset, and stay tuned for updates on our more realistic dataset.

Dataset can be accessd: github.com/YuYifan2000

References

1. Felix Waldhauser, William L. Ellsworth; A Double-Difference Earthquake Location Algorithm: Method and Application to the Northern Hayward Fault, California. Bulletin of the Seismological Society of America 2000;; 90 (6): 1353–1368.
2. Daniel T. Trugman, Peter M. Shearer; GrowClust: A Hierarchical Clustering Algorithm for Relative Earthquake Relocation, with Application to the Spanish Springs and Sheldon, Nevada, Earthquake Sequences. Seismological Research Letters 2017;; 88 (2A): 379–391.
3. Kissling, E., W.L. Ellsworth, D. Eberhart-Phillips, and U. Kradolfer: Initial reference models in local earthquake tomography, J. Geophys. Res., 99, 19635-19646, 1994.
4. Fred Klein, HYPOINVERSE Earthquake Location, Software Release, USGS Digital Object Identifier Catalog, 2019
5. Lomax A., Virieux J., Volant P., Berge-Thierry C. (2000) Probabilistic Earthquake Location in 3D and Layered Models. In: Thurber C.H., Rabinowitz N. (eds) Advances in Seismic Event Location. Modern Approaches in Geophysics, vol 18. Springer, Dordrecht.
6. White, M. C. A., Fang, H., Nakata, N., & Ben-Zion, Y. (2020). PyKonal: A Python Package for Solving the Eikonal Equation in Spherical and Cartesian Coordinates Using the Fast Marching Method. Seismological Research Letters, 91(4), 2378-2389.
7. David R. Shelly; A High-Resolution Seismic Catalog for the Initial 2019 Ridgecrest Earthquake Sequence: Foreshocks, Aftershocks, and Faulting Complexity. Seismological Research Letters 2020;; 91 (4): 1971–1978.

Acknowledgements

The Ridgecrest QTM catalog will be publicly available from the Southern California Earthquake Data Center. All waveform and parametric data are available from the Caltech/USGS Southern California Seismic Network doi:10.7914/SN/CI; stored at the Southern California Earthquake Data Center, doi:10.7909/C3WD3xH1. We would like to acknowledge the use of the SCEC Unified Community Velocity Model Software (Small 2022) in this research. The figures are produced using Generic Mapping Tools and Matplotlib. We are very grateful to all contributors to the softwares we have used in this study as they are all open source and accessible through internet. The whole workflow is available in Yifan Yu's Github respository: https://github.com/YuYifan2000/comparison_hypoDD_GrowClust