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SALSA3D: Updated Tomographic Velocity Models for Improved Travel-Time Prediction and Uncertainty

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Introduction

The ability to accurately locate events of interest is of paramount importance in nuclear explosion monitoring. With this goal in mind, we have developed the first new Sandia and Los Alamos 3D (SALSA3D) P- and S-wave tomographic models since 2017. These new models exhibit a significant reduction in root mean square (RMS) travel-time residual, indicating an improvement in travel-time prediction that should in turn lead to improvements in location accuracy (Begnaud et al., 2020). Here we present the current versions of the new models as well as ongoing efforts towards further improving the models and their travel-time prediction capabilities.

Goal: Improve global slowness tomography models to improve travel-time predictions and thereby location accuracy

P-Wave Model

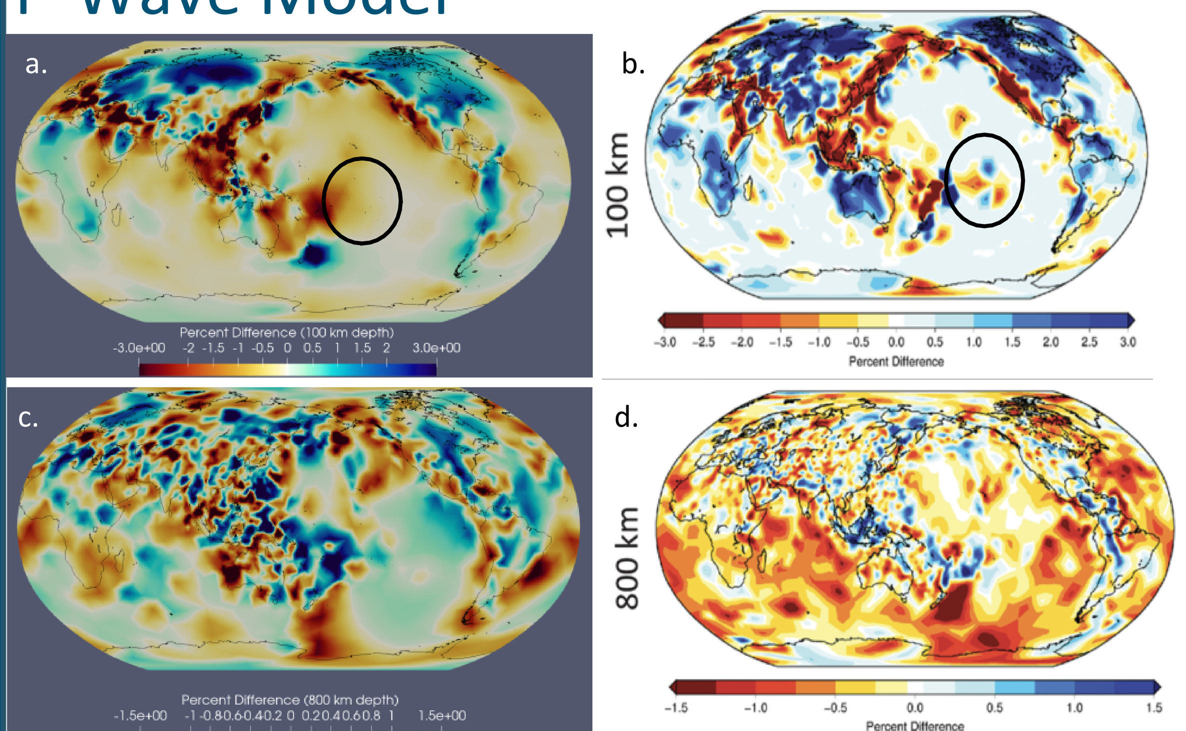

Figure 1. P-wave model at 100 km depth (a) and 800 km depth (c) compared to the Ballard et al. (2016) model (b,d).

- Dataset consisting of 640K events and > 20K stations provided by LANL
- 1,102,045 P and Pn observations from events known to GT25† or better (Bondár et al., 2004) were used in the tomographic inversion after applying significant QC to the dataset, including the removal of observations with significant crustal legs
  - Original publication made model using ~12 million P and Pn observations.
- Model at 100 km (Figure 1a) and 800 km (Figure 1c) depths shown versus model in Ballard et al. (2016; Figures 1b, 1d, respectively)
  - Despite using fewer observations, the new models achieve a similar amount of detail as the old models while notably reducing artifacts (e.g., area circled in black at 100 km depth)
- Resolution is also improved in the new model (see Figure 2).
  - This increase in resolution is likely a result of the inclusion of new stations and events, resulting in novel raypaths that sample areas that previously had little to no data
- We observe a decrease in travel-time RMS residual (Figure 3; green) vs the Ballard et al. (2016) model (Figure 3; orange), going from a value of 1.49 to 1.2 at the same tomographic iteration (a reduction of 20%)

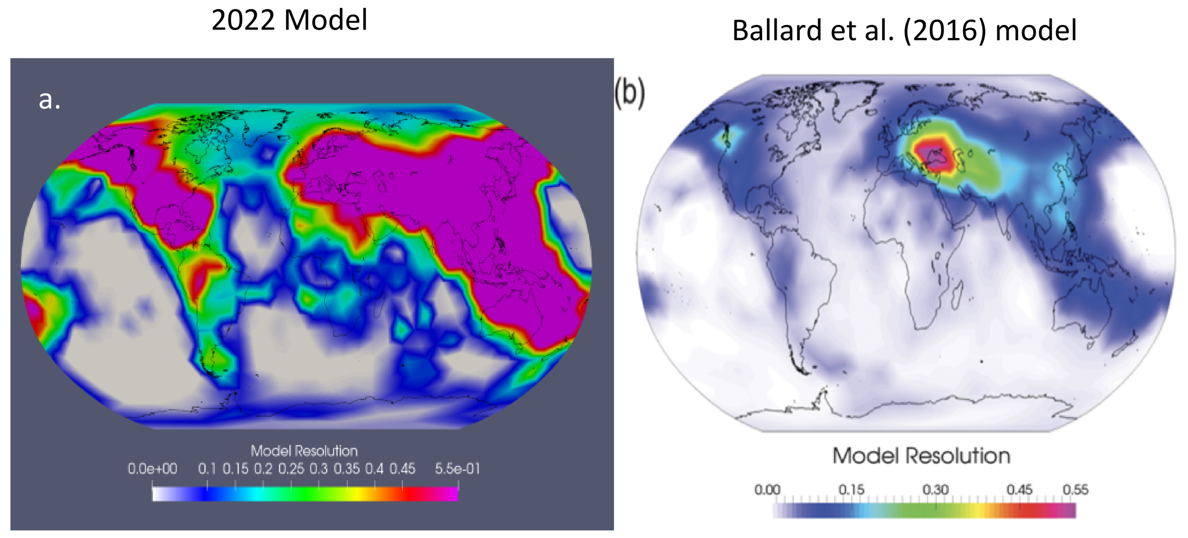

Figure 2. P-wave model resolution at 800 km depth prior to grid refinement (a) compared to the Ballard et al. (2016) model (b). Note the difference in scale.

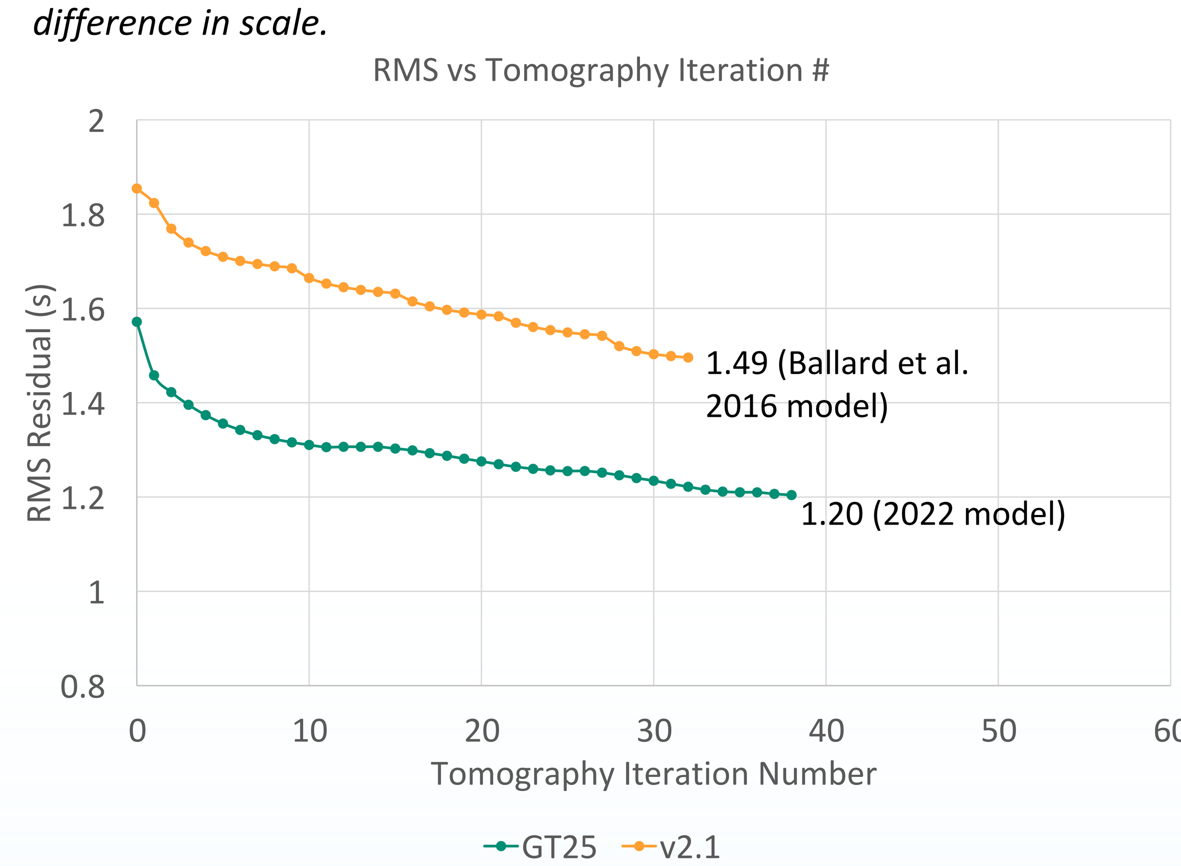

Figure 3. Travel-time RMS residual in seconds vs tomographic iteration of the 2022 SALSA3D P-wave model (green) vs the 2016 Ballard et al. model (orange), with final values shown on plot.

† A Ground Truth (GT) value quantifies location uncertainty, with higher GT values having higher uncertainty. For example, a GT10 event has an epicentral location known to 10 km within a 95% confidence level (Bondár et al., 2004).

S-Wave Model

- 97,984 S and Sn observations were used to generate the S-model after the same QC as the P-wave model was applied
- Once again, we see a large model improvement despite using fewer observations, with the unpublished 2014 model using 1.6 million observations
- Note significant reduction in artifacts, particularly in areas with little to no data (e.g., the oceans)

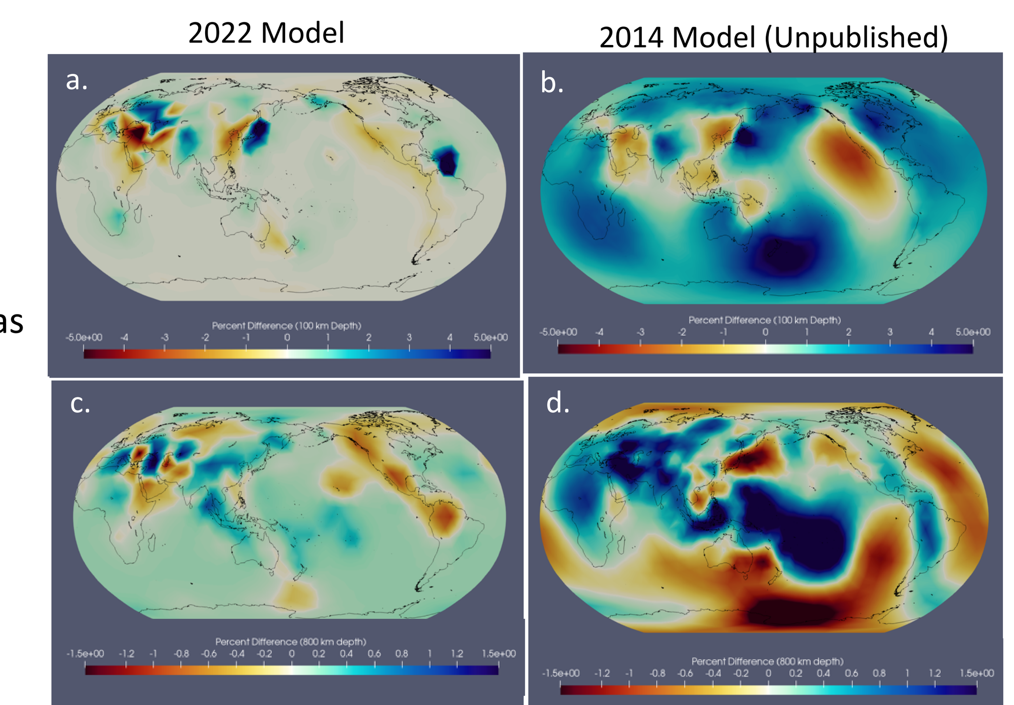

Figure 4. S-wave model at 100 km depth (a) and 800 km depth (c) compared to unpublished 2014 model (b,d).

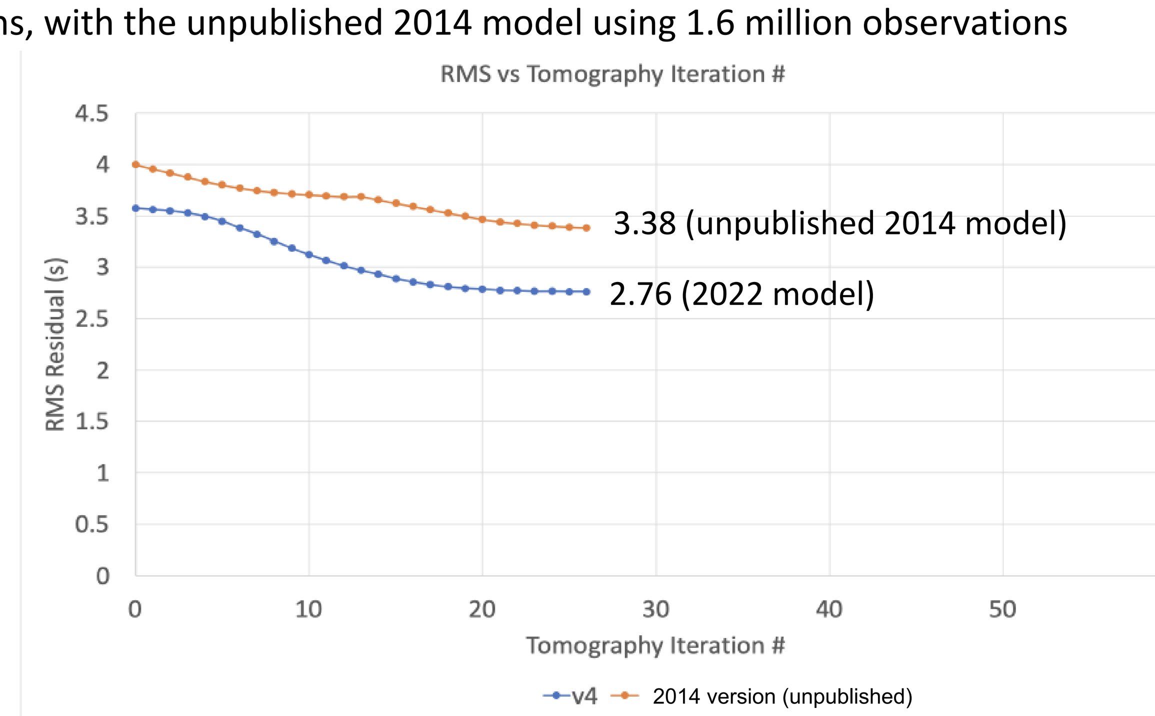

Figure 5. Travel-time root mean square (RMS) residual in seconds vs tomographic iteration of the 2022 SALSA3D S-wave model (blue) vs the unpublished 2014 model (orange), with final values shown on plot.

Path Dependent Uncertainty

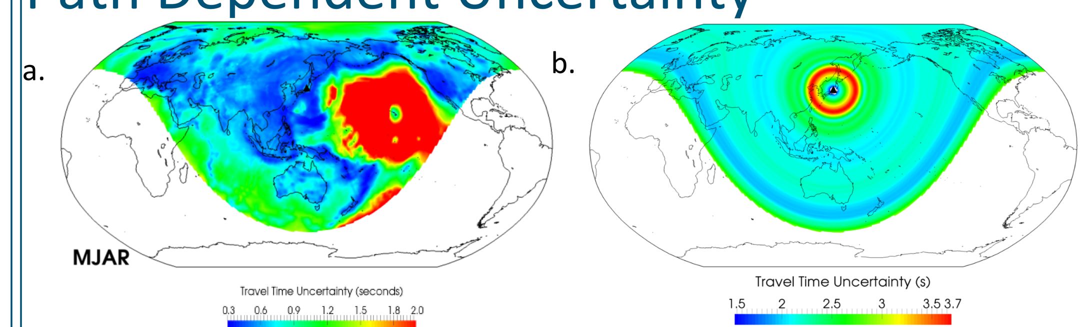

Figure 6. Path-dependent uncertainty for station MJAR (a) vs 1D distance-dependent uncertainty for the same station (b) taken from Ballard et al. (2016)

- In future work, path dependent uncertainties for the 2022 SALSA3D models will be calculated.
- SALSA3D makes use of the full covariance matrix to calculate these uncertainties, which are much more realistic than more typical 1D distance-dependent uncertainties.

Summary Rays

- The LANL dataset contains a large number of GT50† observations that are currently unused. GT50 observations are highly redundant (i.e., computationally expensive) and have higher travel-time uncertainties individually.
- These data may be able to provide novel raypaths to the model, so we are investigating the use of summary rays which represent the average of travel-times recorded at a station from co-located or nearly co-located events (Hariharan et al., in prep).

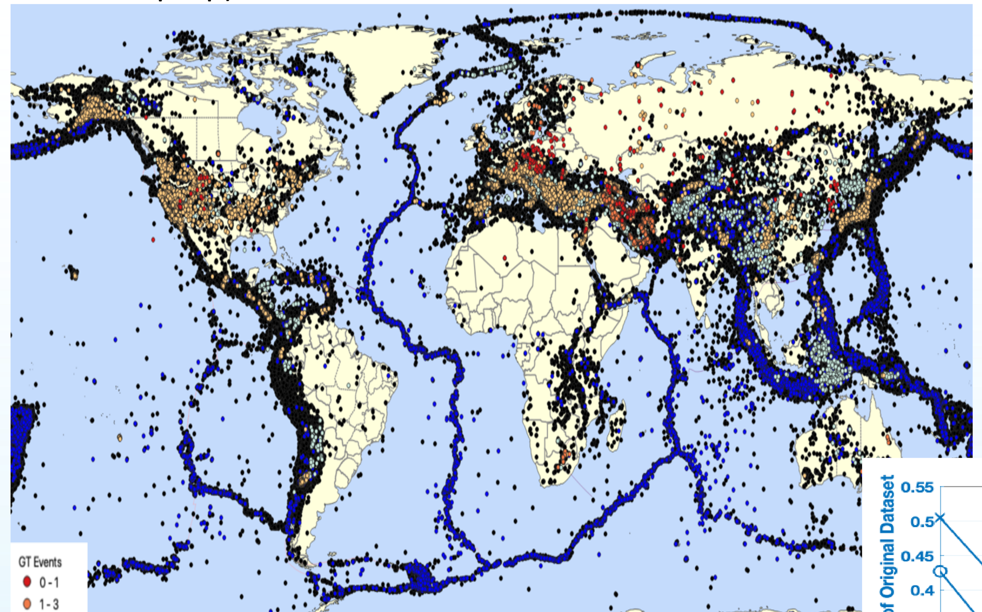

Figure 7 (above). Map of events in 2022 dataset with GT (Bondár et al., 2004) indicated by color. Note the high number of GT50 events (black).

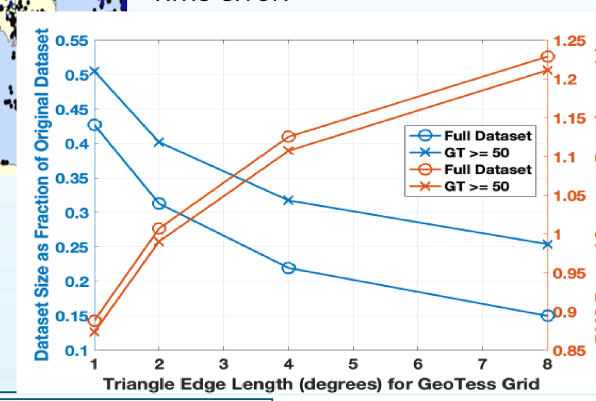

Figure 8. Comparison of dataset size (blue) vs RMS error of summary rays in seconds (orange), with both curves shown vs model grid size (x-axis). Circle markers indicate the full dataset was used; x markers indicate only GT50 data were used. We observe a significant reduction in dataset size can be achieved without causing a significant increase in RMS error.

OBS Data and SMART Cables

- Another area of improvement is the inclusion of ocean bottom seismometer (OBS) data.
- In Rowe et al. (2021), it was demonstrated that the inclusion of hypothetical OBS locations (i.e., SMART cables) in the Ballard et al. (2016) SALSA3D model would significantly increase resolution and reduce uncertainties over oceanic paths.
- In the near future, OBS data from LANL will be included in the SALSA3D models (Rowe et al., in prep)

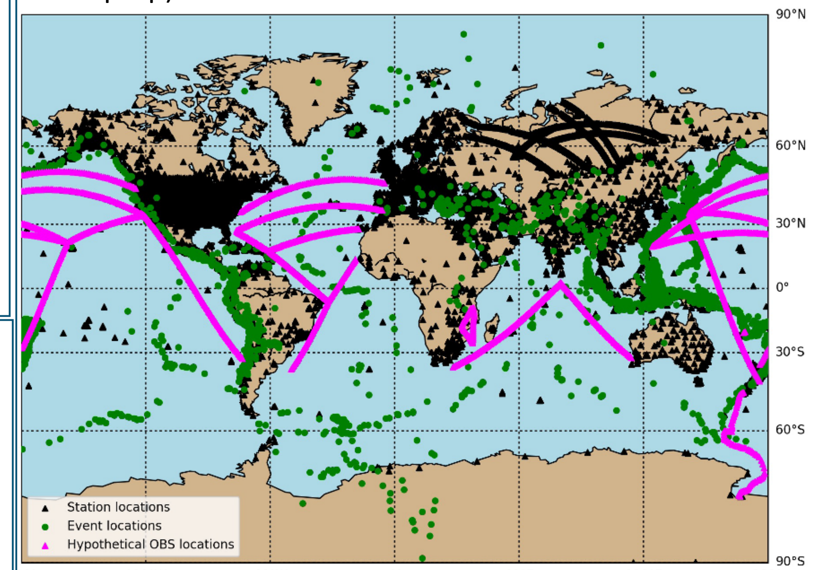

Figure 9. Station locations (black triangles) and event locations (green circles) used to generate the 2016 SALSA3D model and hypothetical SMART cable locations (pink triangles).

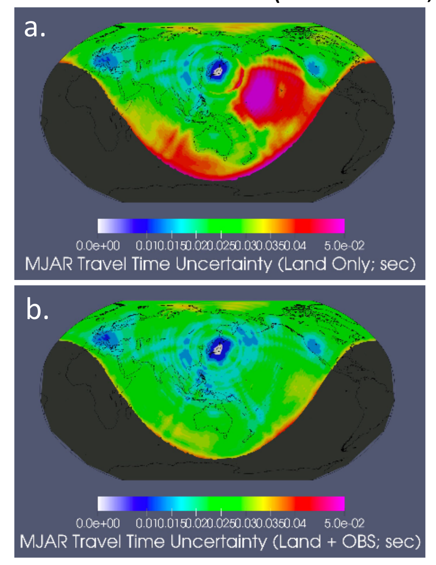

Figure 10. Travel-time uncertainty at station MJAR without (a) and with (b) the inclusion of hypothetical SMART cables. Absolute uncertainty values are currently underestimated due to choice of model damping parameters, but qualitative patterns and relative values would not change.

Conclusions and Future Work

- **Despite the use of fewer observations, we see a substantial increase in resolution and decrease in travel-time RMS residuals in the new SALSA3D P-wave and S-wave models as compared to previous versions. We expect these improvements to result in improved location accuracy.**
- **We will further improve upon the models via:**
  - **Further iterations and investigation of damping parameters**
  - **Including more observations in the dataset by including summary rays and/or modifying current QC parameters**
  - **Including OBS data in our current dataset**
- **Using a subset of low-GT events with high-confidence hypocenters, the models will be applied to evaluate the success of new SALSA3D models and their travel-time predictions in providing better source locations**

References

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