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Insights from summary ray calculations on the SALSA3D global dataset

S15B-02

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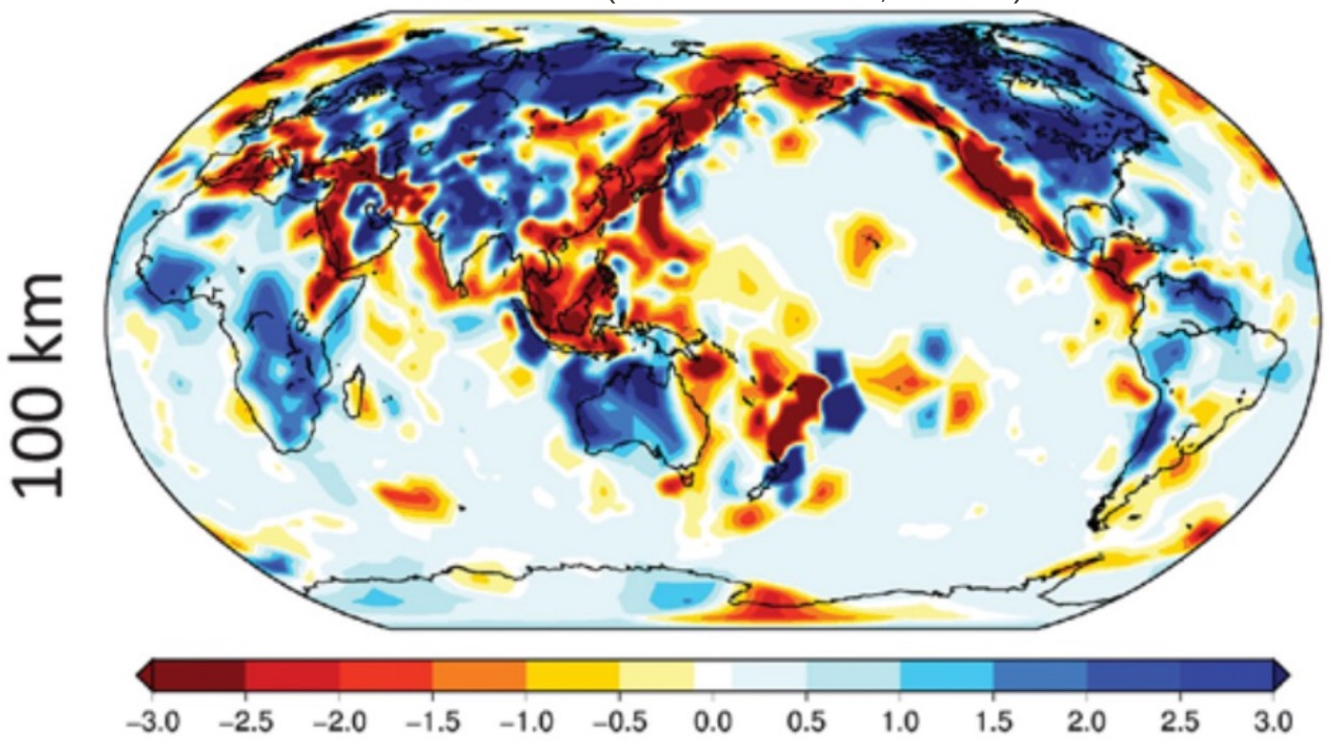
SALSA3D: Tomographic Velocity models for Improved Traveltime Prediction and Uncertainty

- Tomographic models contribute to our ability to **accurately locate events** and characterize event origin (natural or man-made) and provide information for **attribution of potential nuclear events**
- Improvements in locating explosions require accurate predictions of travel-times in a 3D, heterogeneous Earth

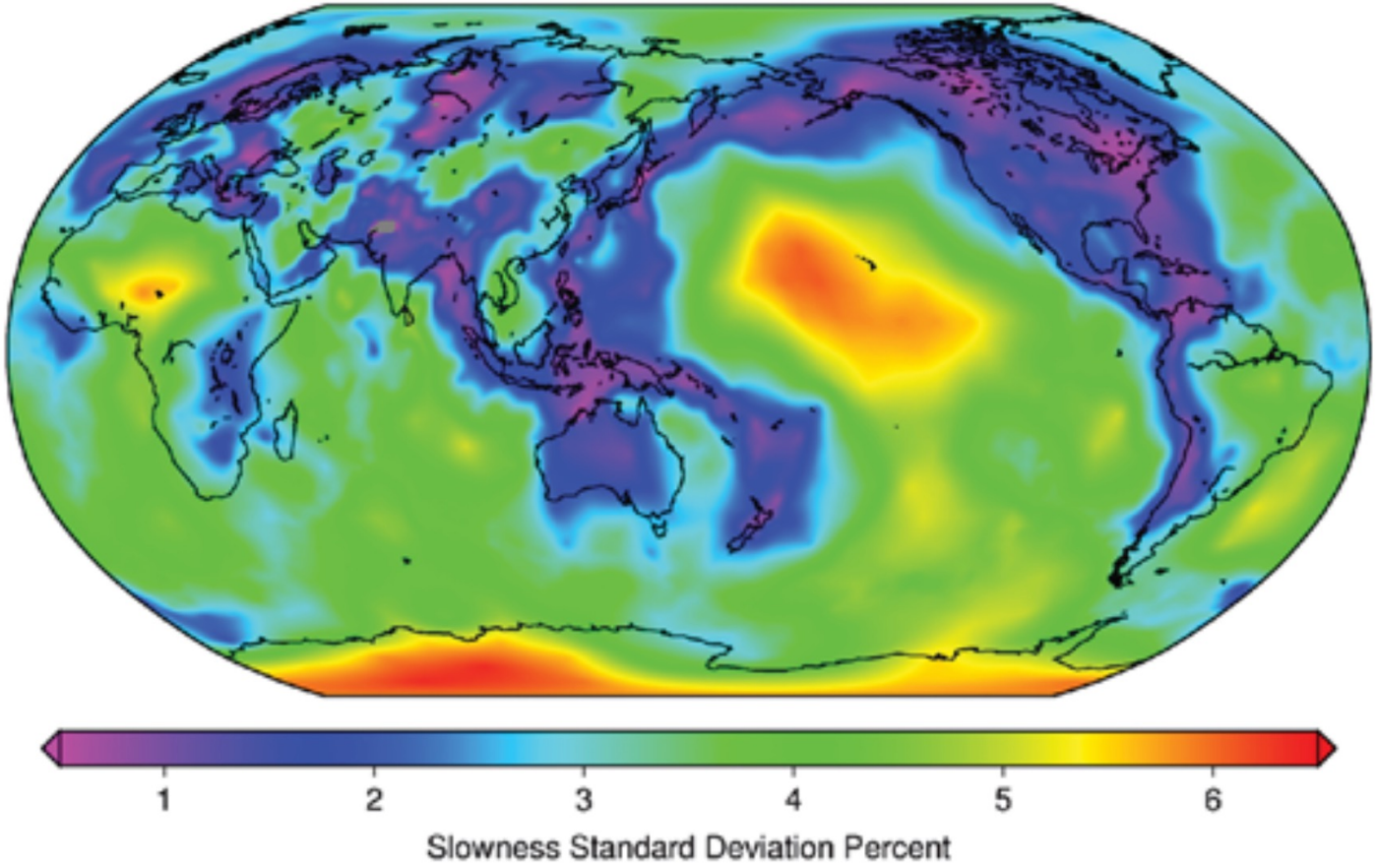
SALSA3D (Ballard et al., 2016)



SALSA3D is available at: http://ds.iris.edu/ds/products/emc-salsa3d/ and https://www.sandia.gov/salsa3d/

SALSA3D: Tomographic Velocity models for Improved Traveltime Prediction and Uncertainty

- **Improvements in locating explosions** require:
  - **Accurate predictions of travel-times** in a 3D, heterogenenous, Earth
  - Improved uncertainty quantification for travel-time predictions: Weighting residuals by a more informed uncertainty can **change absolute locations as well as location uncertainty**



$$\sigma_{r,i} = \sqrt{\sigma_{d,i}^2 + \sigma_{F,i}^2}$$

Composite uncertainty used in earthquake location, incorporating measurement and prediction terms

SALSA3D: Tomographic Velocity models for Improved Traveltime Prediction and Uncertainty

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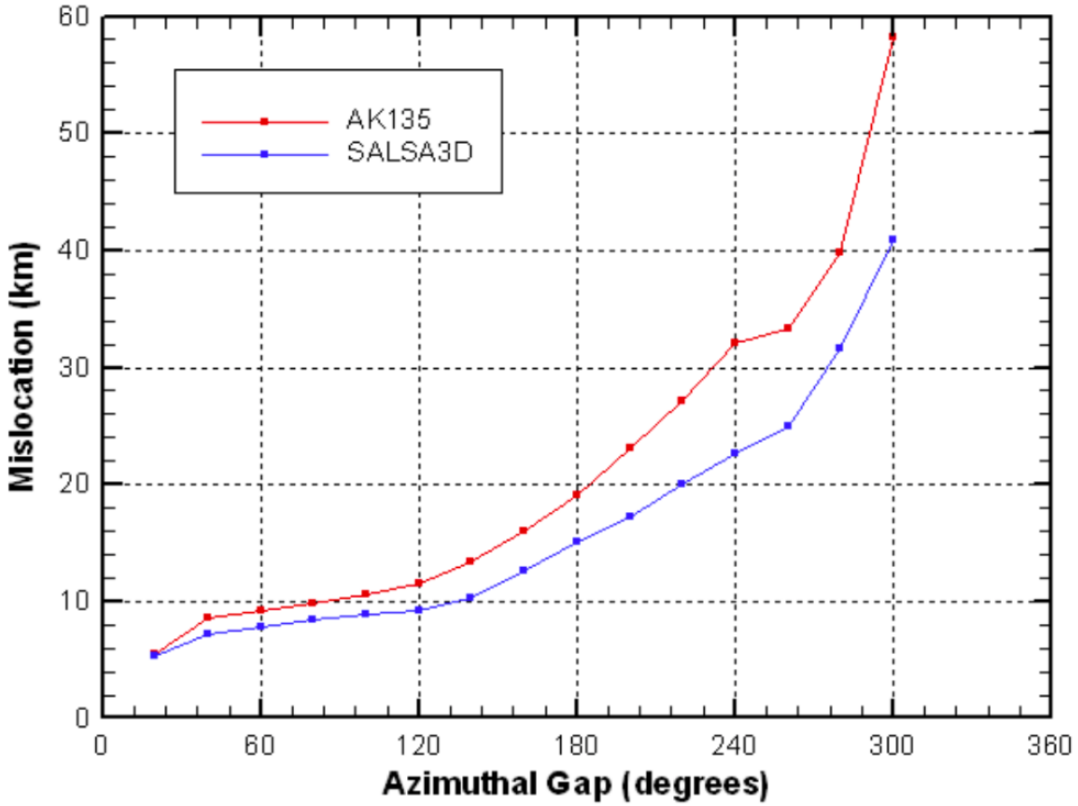
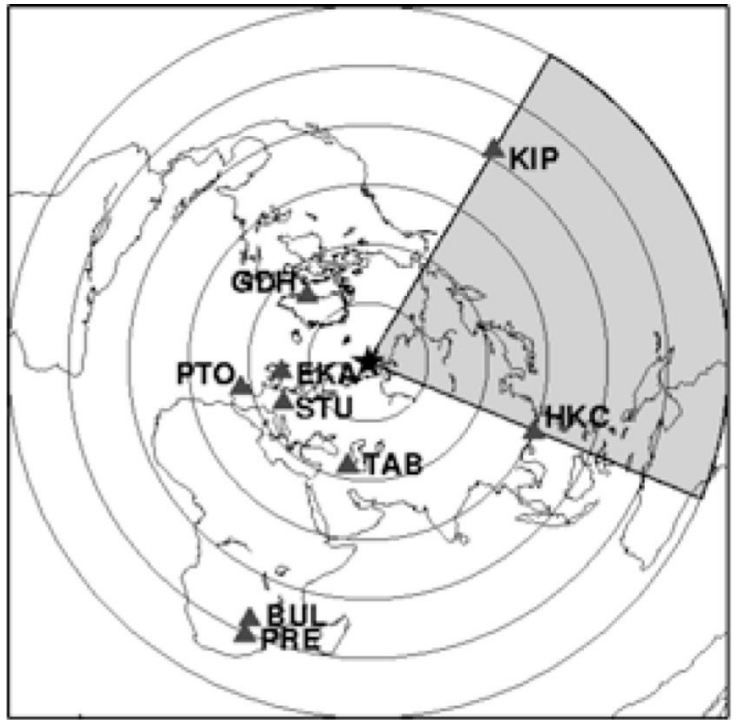


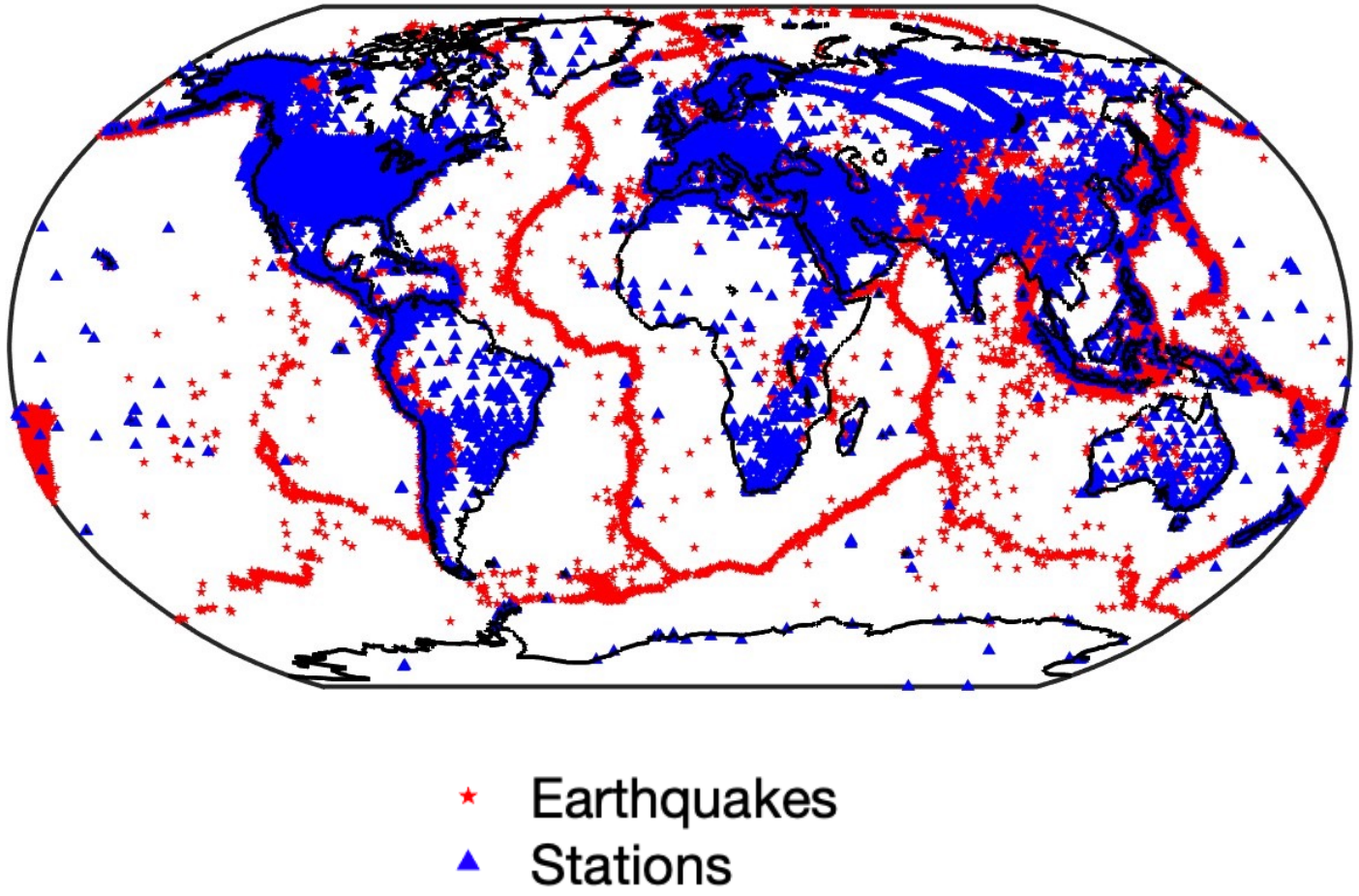
Begnaud et al., 2011

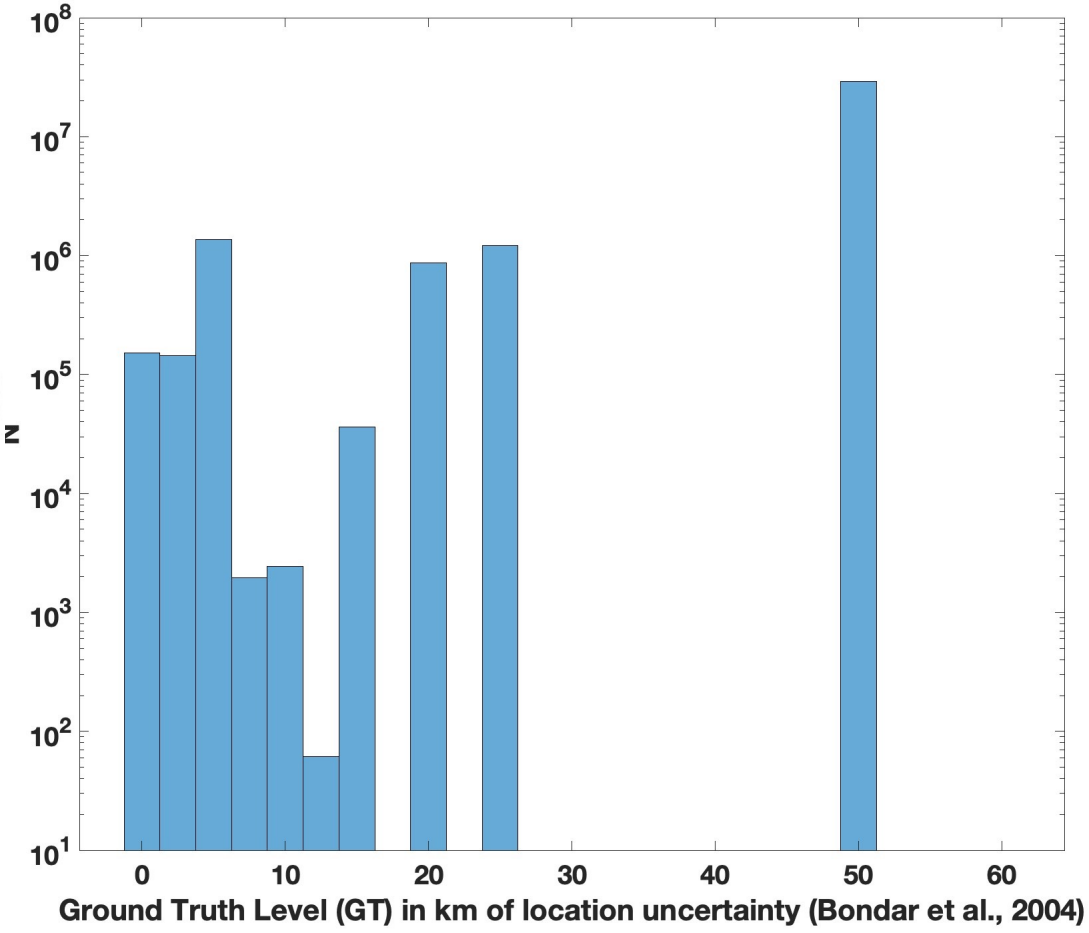


Bondar et al., 2004

SALSA3D: An Example of a "Big Data" Challenge in Seismology

- A dataset of ~33 million P and Pn travel-time measurements
- Redundant raypath coverage due to inhomogeneous station/event distribution





Challenges with Global Tomographic Inversions

N(entries) increases linearly with dataset size

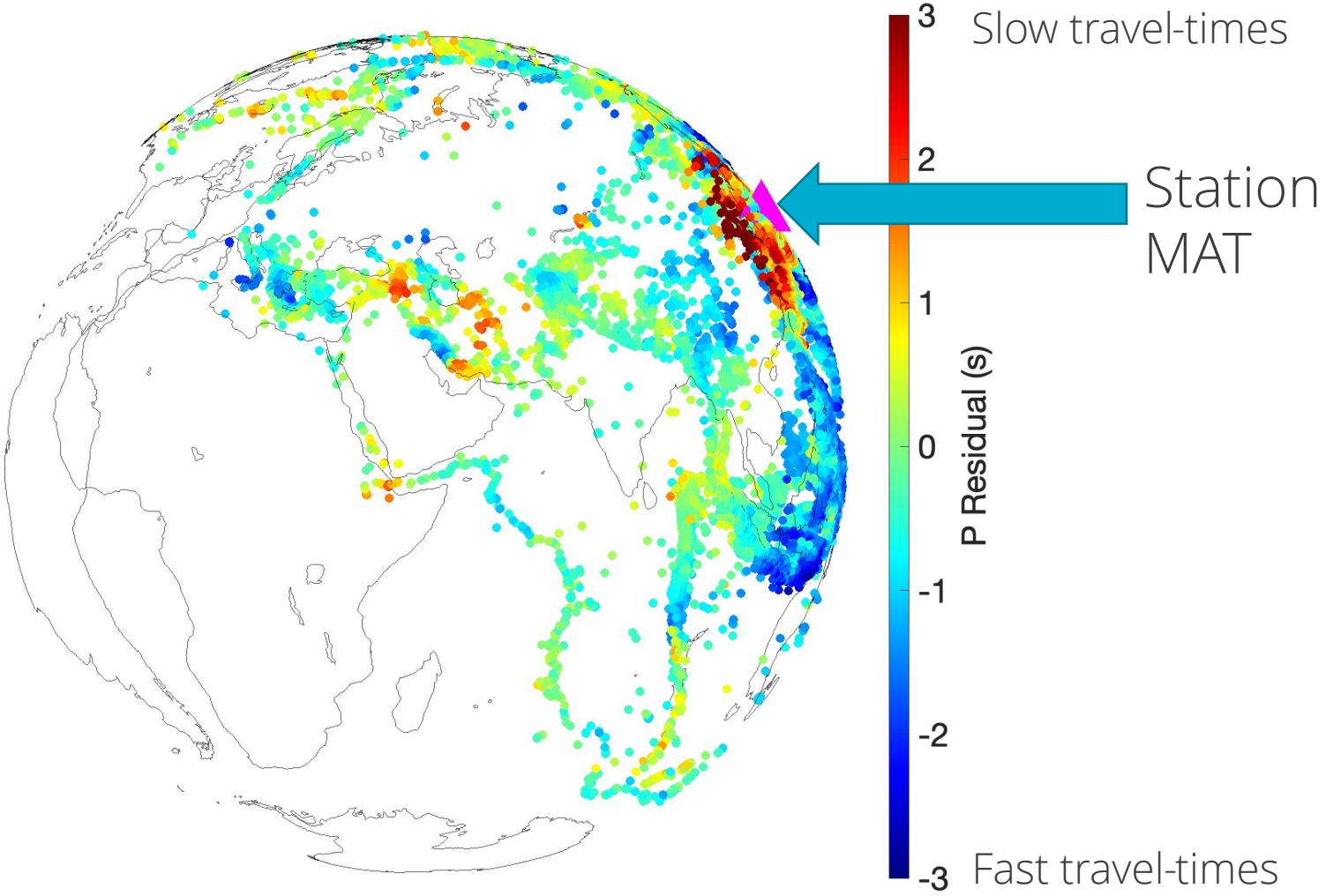
N(entries) increases quadratically with dataset size

$$\begin{bmatrix} \mathbf{C}_d^{-1/2}\mathbf{A}(\mathbf{m}) \\ \mathbf{C}_m^{-1/2} \end{bmatrix} \mathbf{m} = \begin{bmatrix} \mathbf{C}_d^{-1/2}\mathbf{d} \\ \mathbf{C}_m^{-1/2}\mathbf{m}_0 \end{bmatrix}.$$

Summary Rays

- Summary Rays allow for **down-sampling** of a travel-time dataset

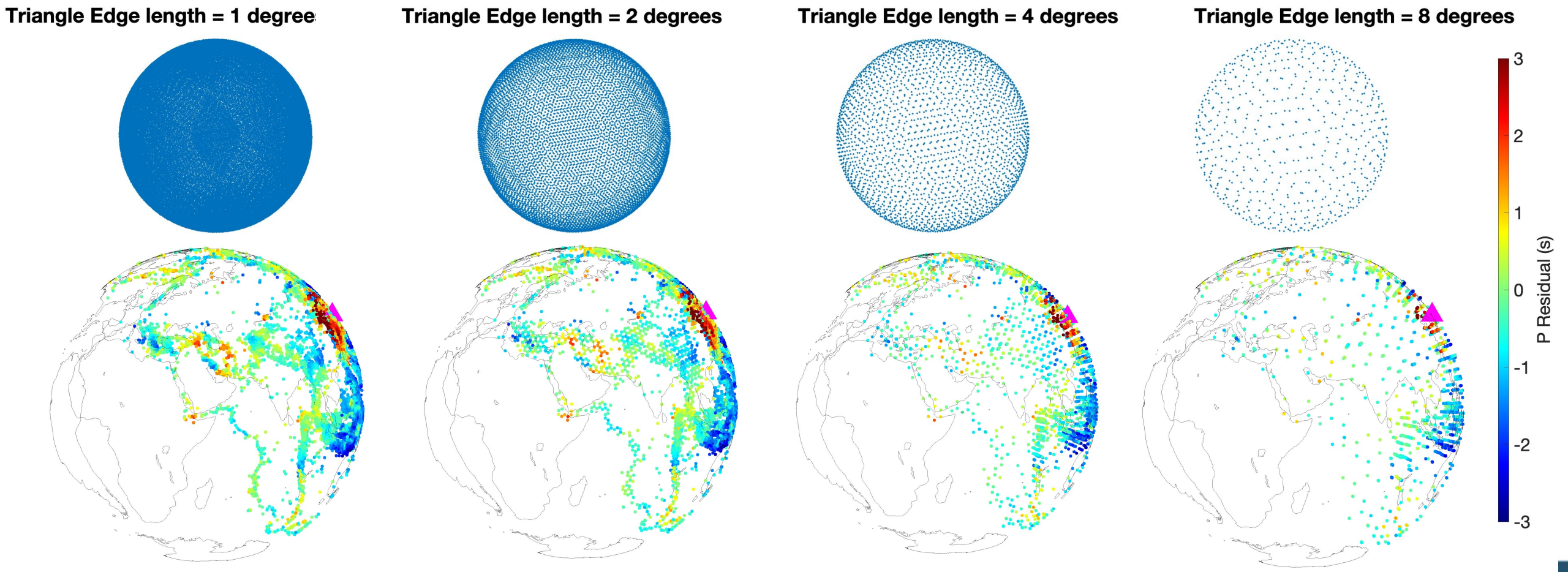
Example of travel-time measurements at a single station (MAT: Japan)



The Summary Ray Process: Example Case

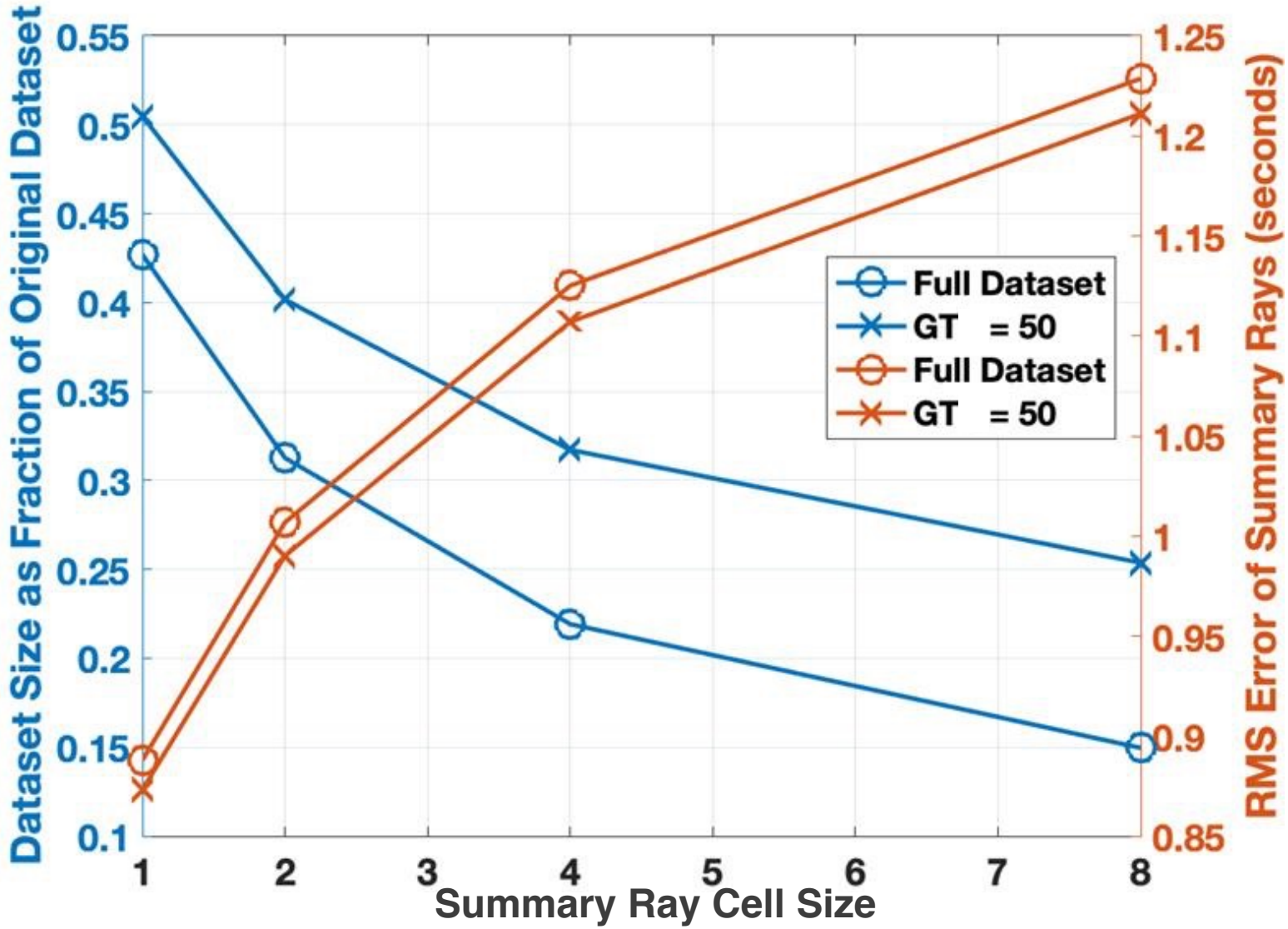
- We implement a workflow that (1) identifies clusters of traveltimes in equal-area cells, and (2) averages these measurements

Summary Rays for Station MAT

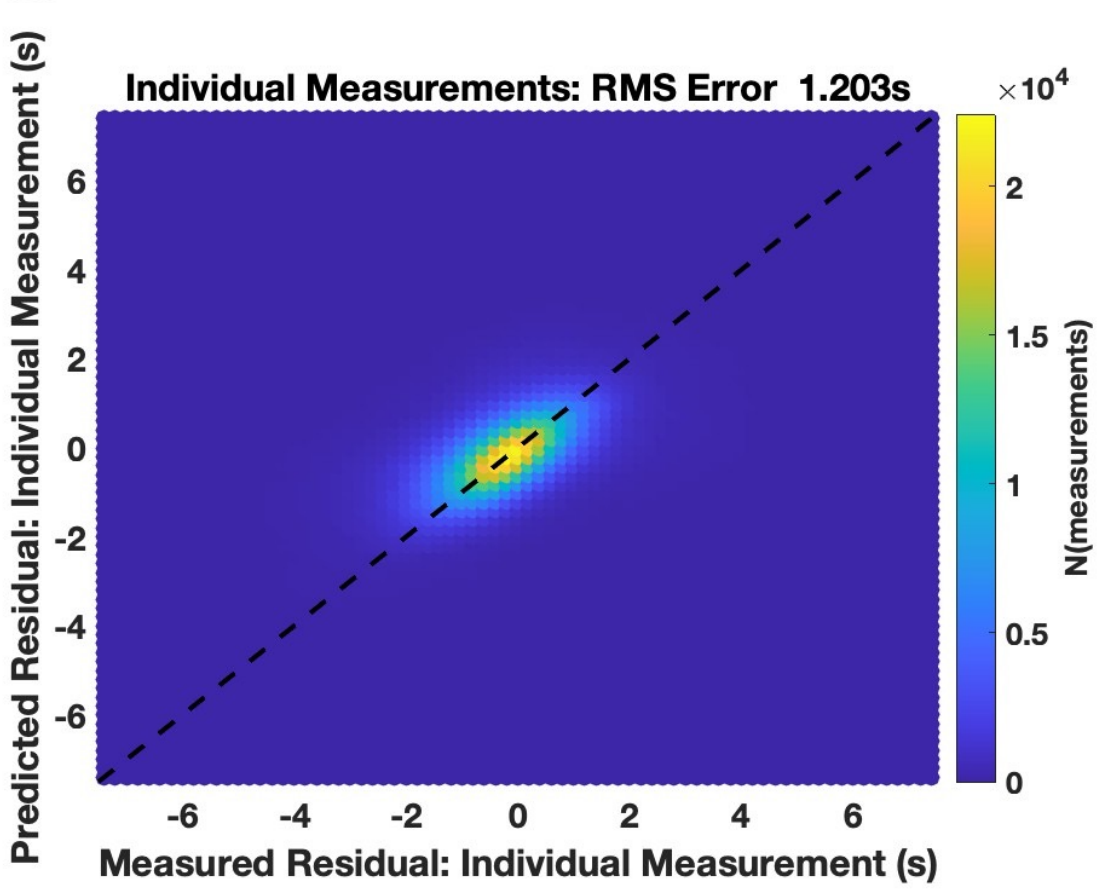


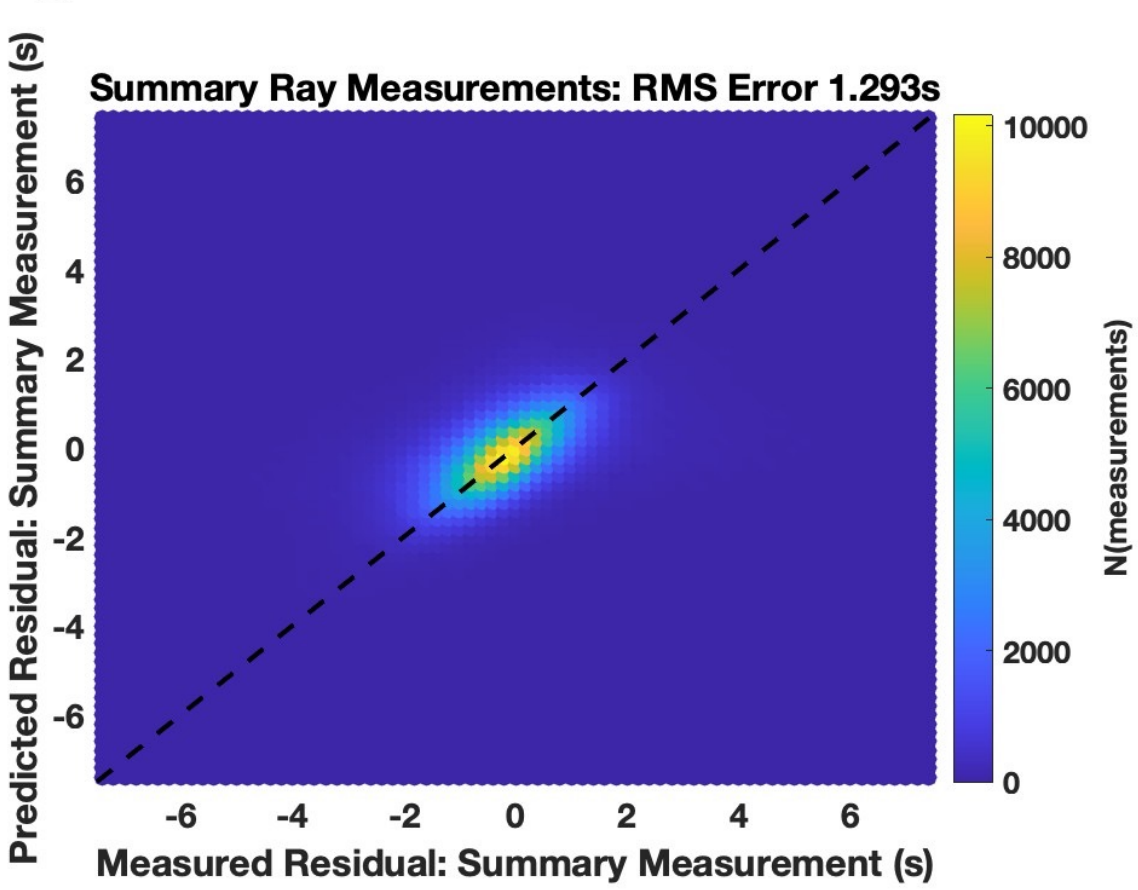
Impact of Summary Rays on a Contemporary Global Body-Wave Dataset

- Successfully able to truncate the SALSA3D dataset by a factor of 2 at the smallest ray bundle size
- Size of the truncated dataset trades off with the ability of summary rays to accurately represent data



Summary Ray Consistency with Tomographic Predictions

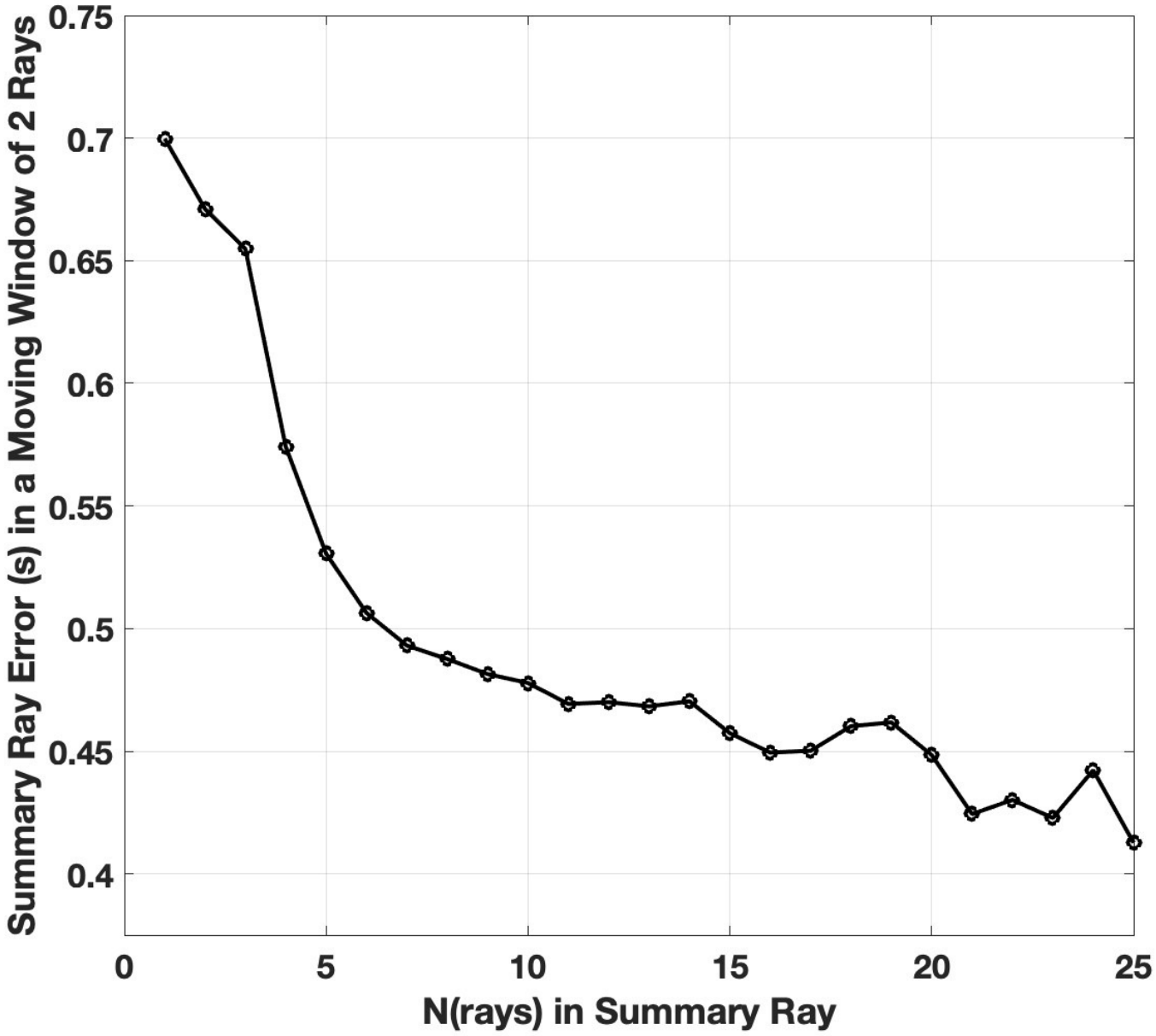




- We compare the summary ray calculations with co-located predictions from a tomographic model generated without using summary rays
- Summary rays fit the model almost as well as the data used to construct the model itself

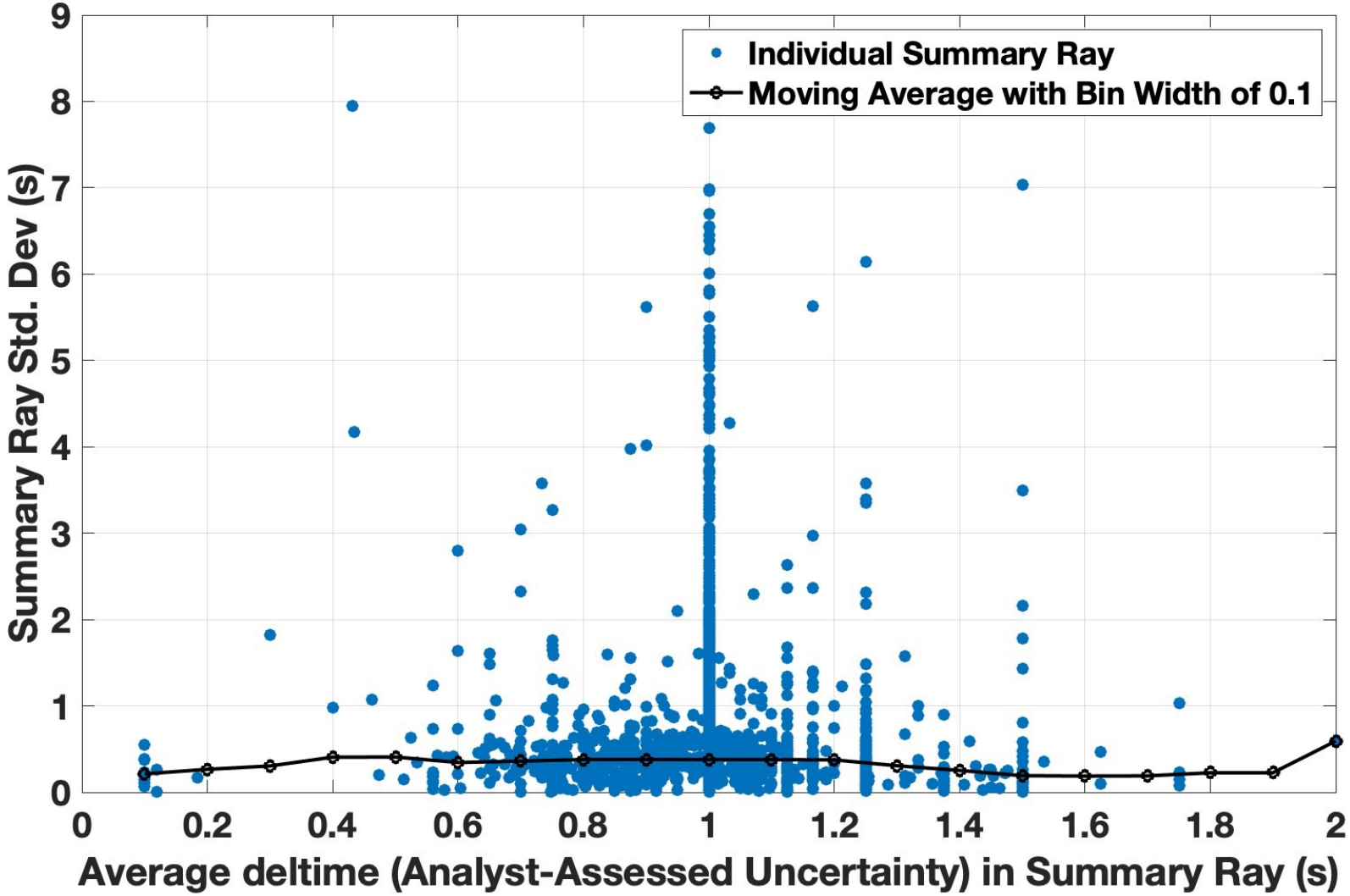
Summary Ray Consistency with Tomographic Predictions

- Summary rays with more rays in the ray bundle exhibit a sharp increase in accuracy as the ray bundle includes > 4 rays



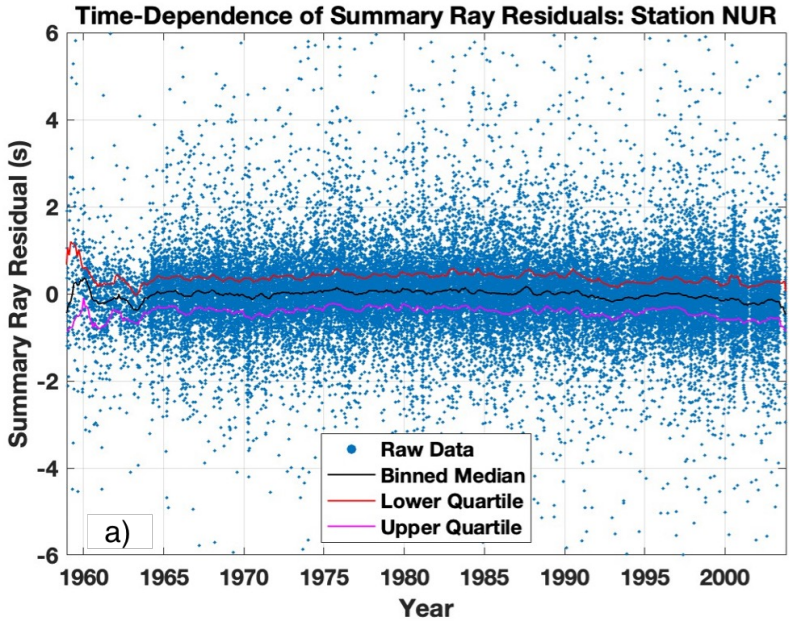
An Alternate Perspective on Data Uncertainty from Summary Rays

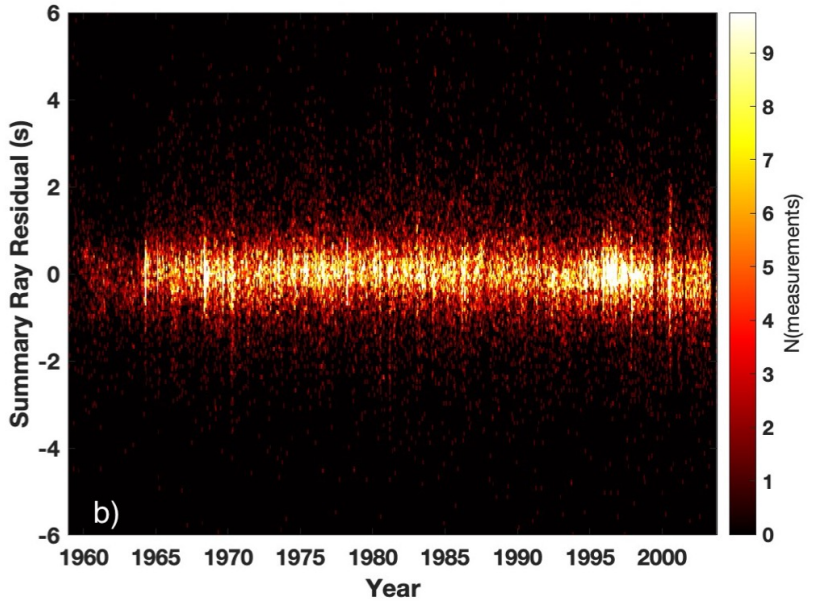
- **Two metrics** of data uncertainty
  - Standard deviation of summary ray residuals
  - Analyst-derived uncertainty on each individual measurement
- **Little agreement** between summary ray uncertainty and measurement uncertainty
  - Analyst uncertainties do not reflect true sources of scatter in measurements

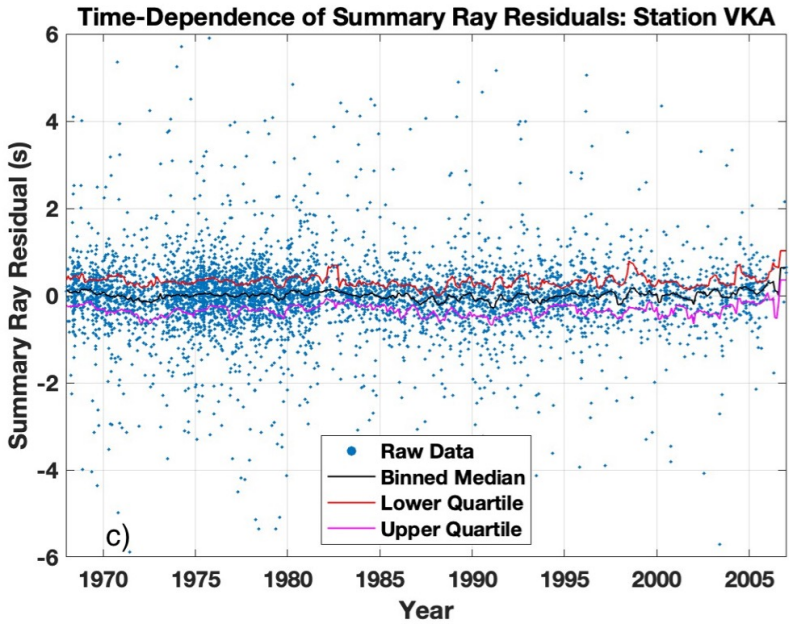


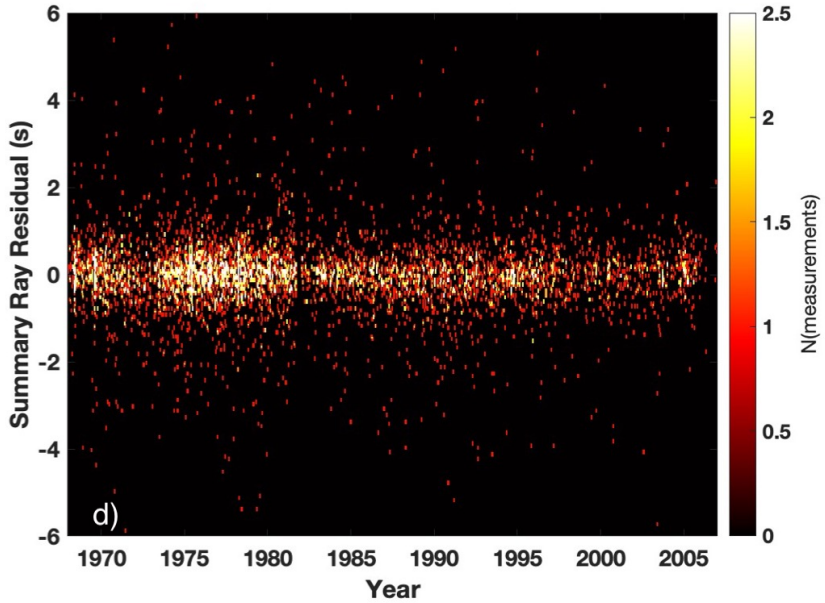
A Perspective on Systematic Timing Errors from Summary Rays

- Differences between travel-time measurements and their corresponding summary rays should be **independent of time**
- This is the case for **most** stations
- We study the summary ray travel-time 'residuals' as (Residual = $T_{summary\ ray} - T_{measurement}$)

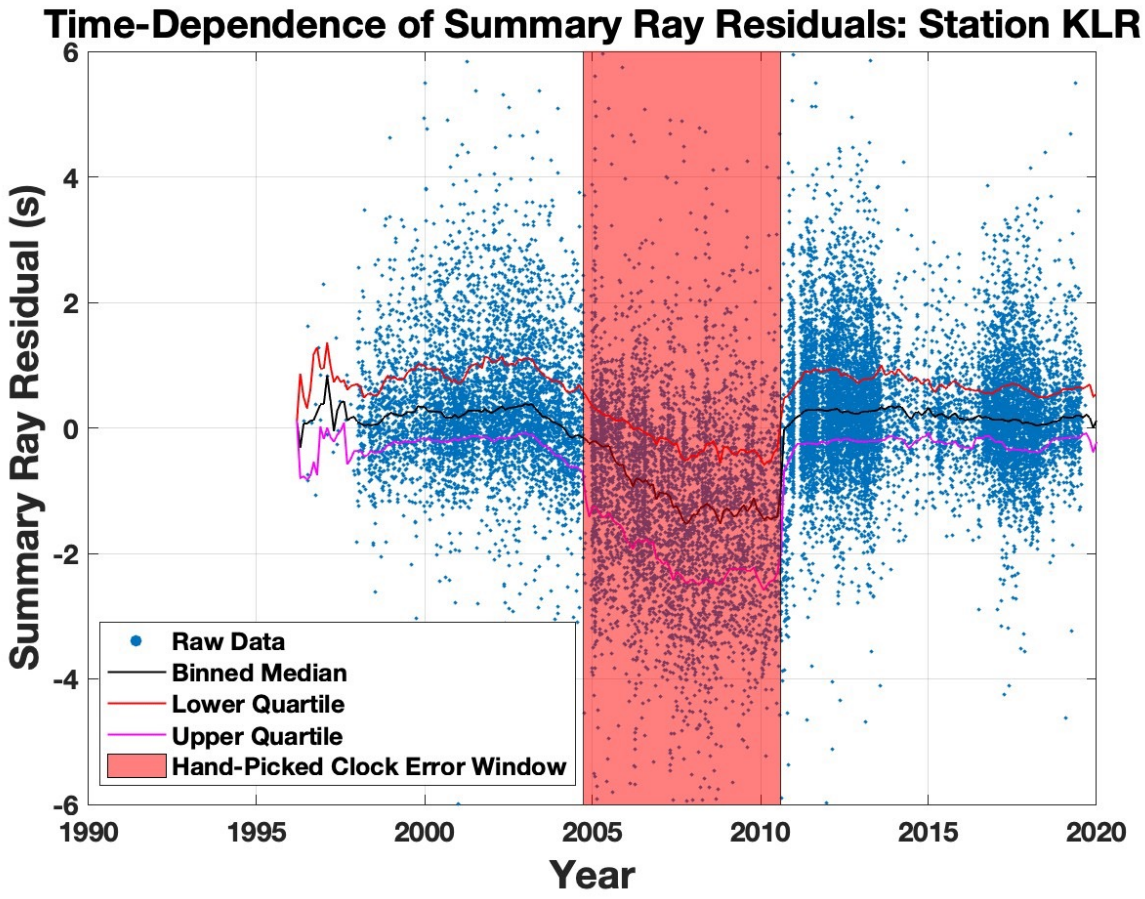


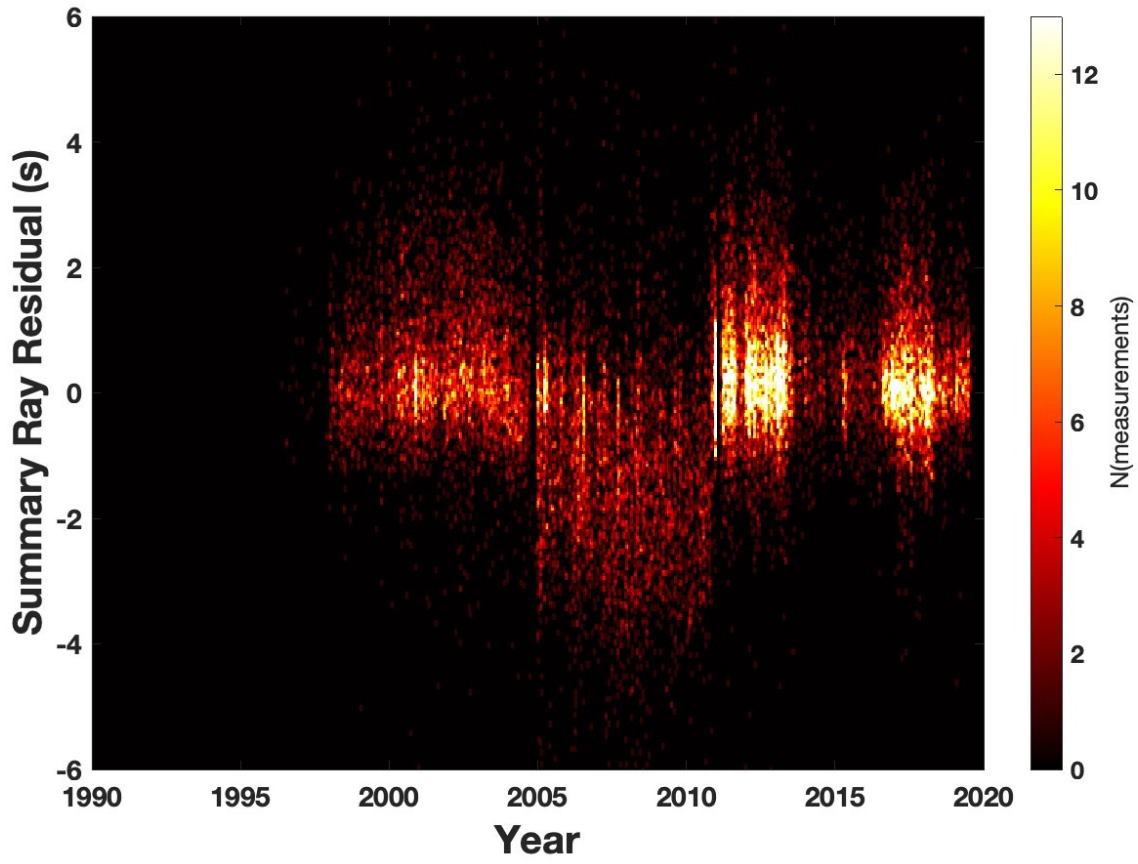






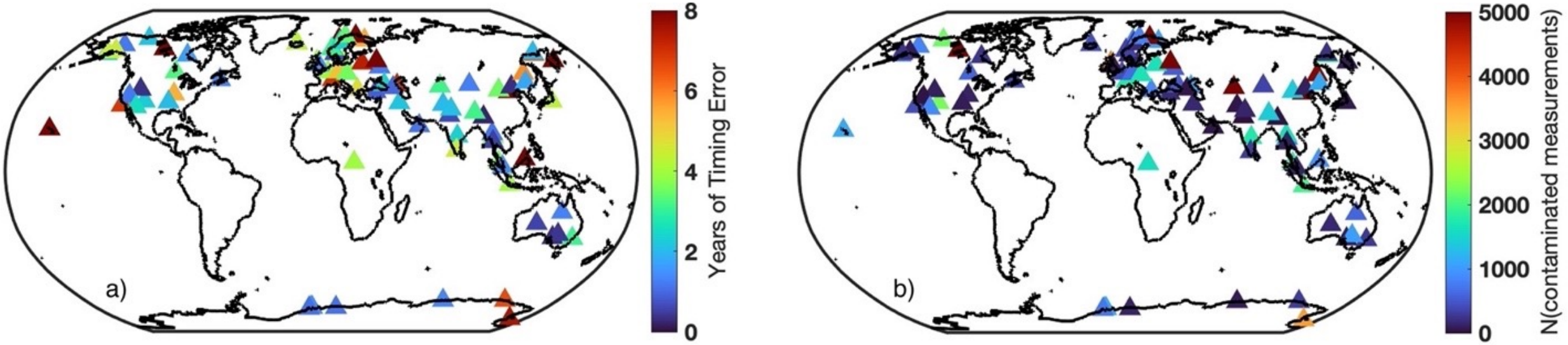
A Perspective on Systematic Timing Errors from Summary Rays





- Several stations show **substantial deviations** relative to the background value

An Up-to-date Database of Timing Errors Across Global Stations



- The timing errors we identify impact
  - **106,024 measurements** (0.46% of all measurements)
  - **83 stations** (0.56% of all stations)

Conclusions

- We find that the current event/station distribution allows for global body-wave dataset size to be decreased by nearly 50% via summary rays
- Summary rays are consistent with predictions from a model generated using the full dataset, and show increasing accuracy as the number of rays in the ray bundle increase
- Current body-wave traveltime datasets may be impacted by systematic timing errors due to factors such as clock errors; we have generated an up-to-date catalog of these errors
- We plan to extend our analysis to S-waves and explore tomographic inversions conducted using the summary ray datasets