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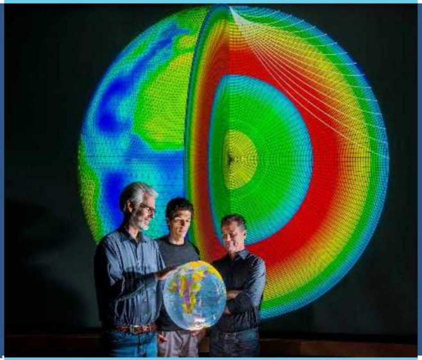
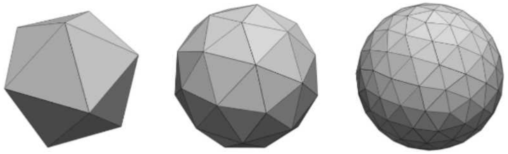
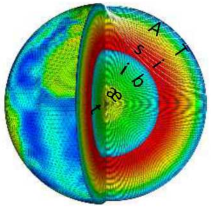
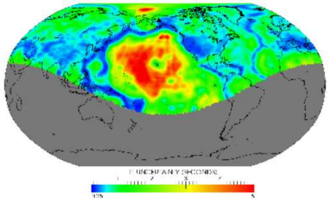
SALSA3D









PRESENTED BY

Sandy Ballard

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SALSA3D

A Global 3D Velocity Model of the Earth's Mantle For Improved Seismic Event Location in Nuclear Explosion Monitoring

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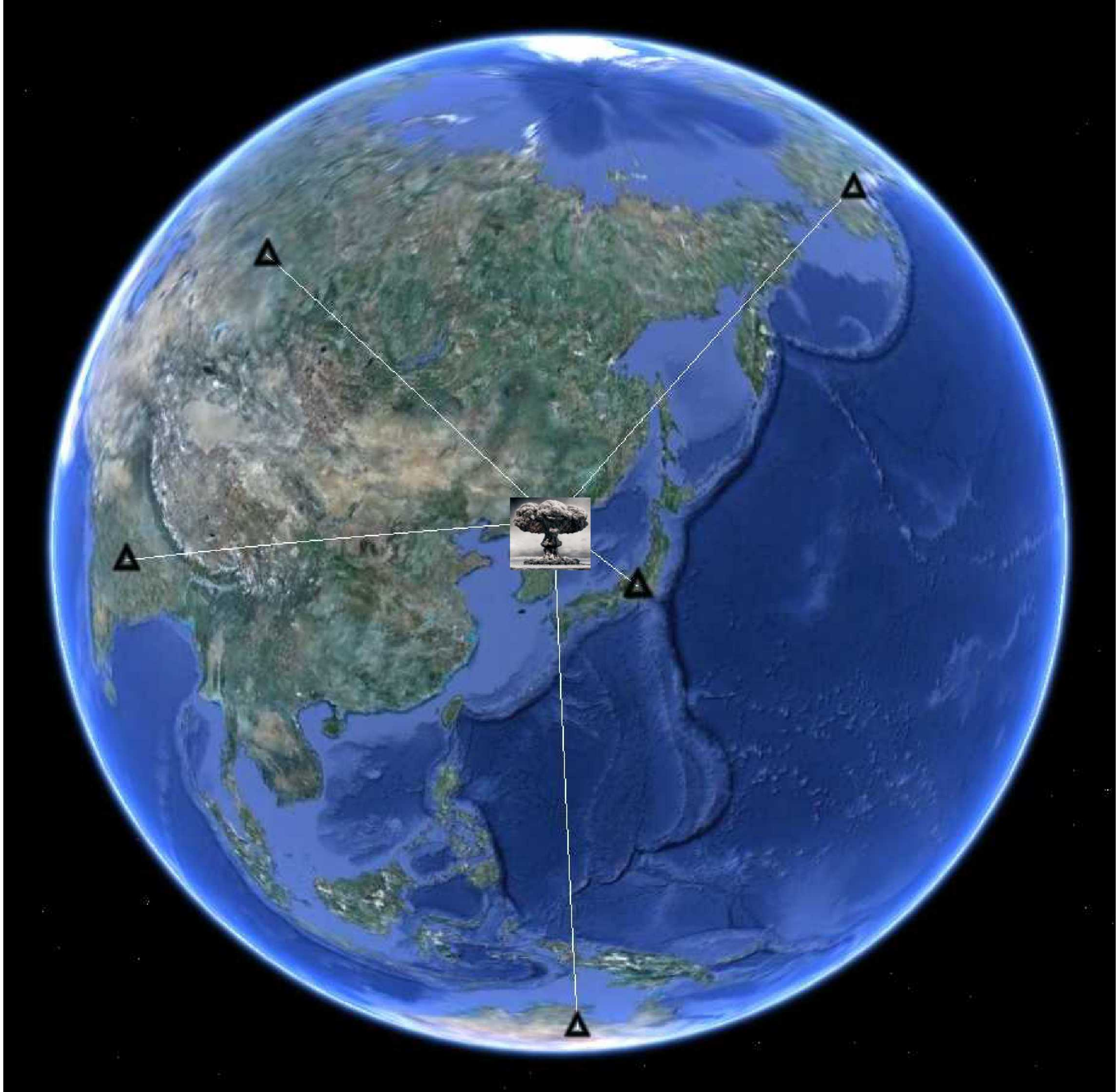
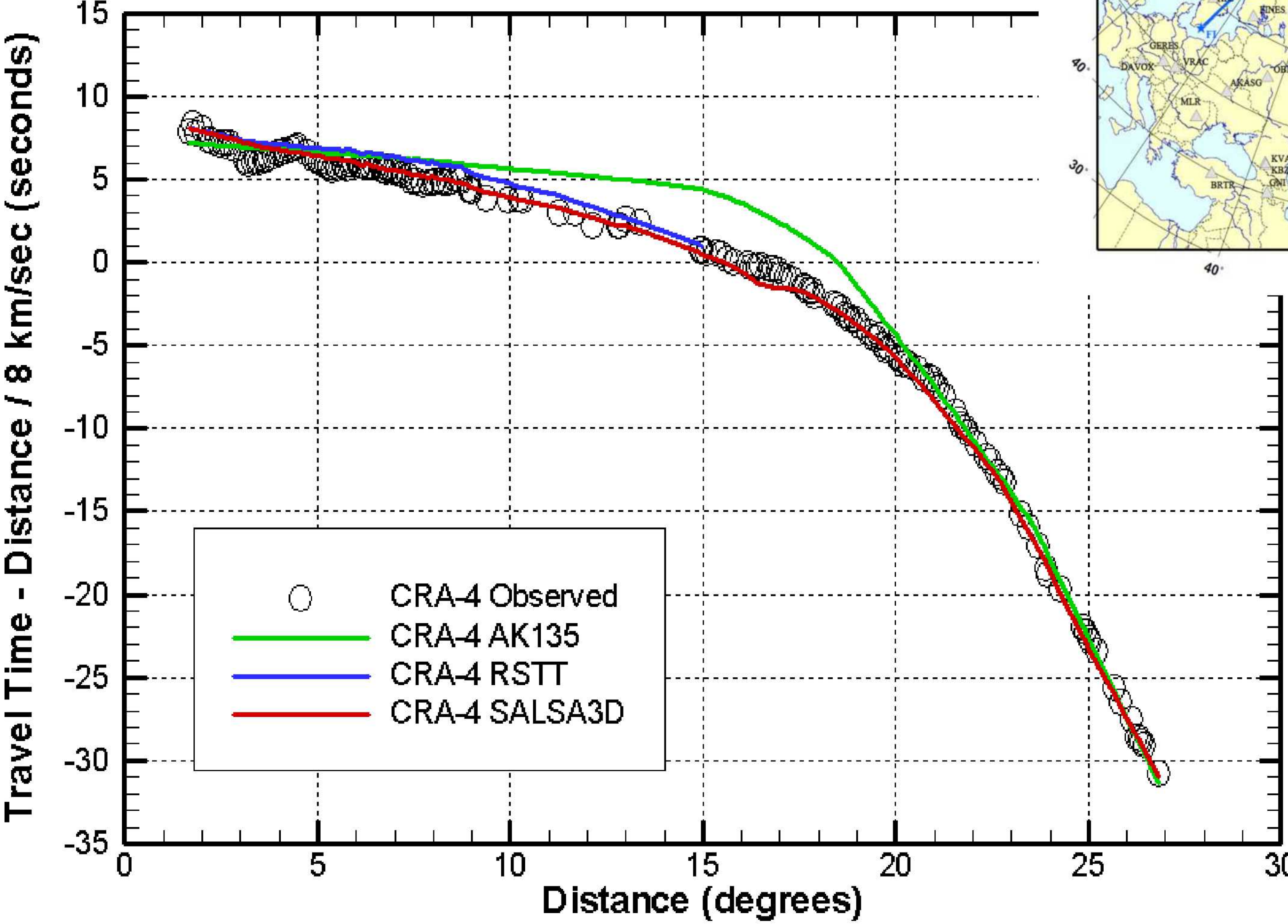
Outline

- Motivation
- Data Set
- Tomographic Procedure
- Model Resolution and Adaptive Gridding
- Velocity Model and Uncertainty
- Predicted Travel Times and Uncertainty
- Location Accuracy Improvement



Deep Seismic Sounding (DSS) Lines

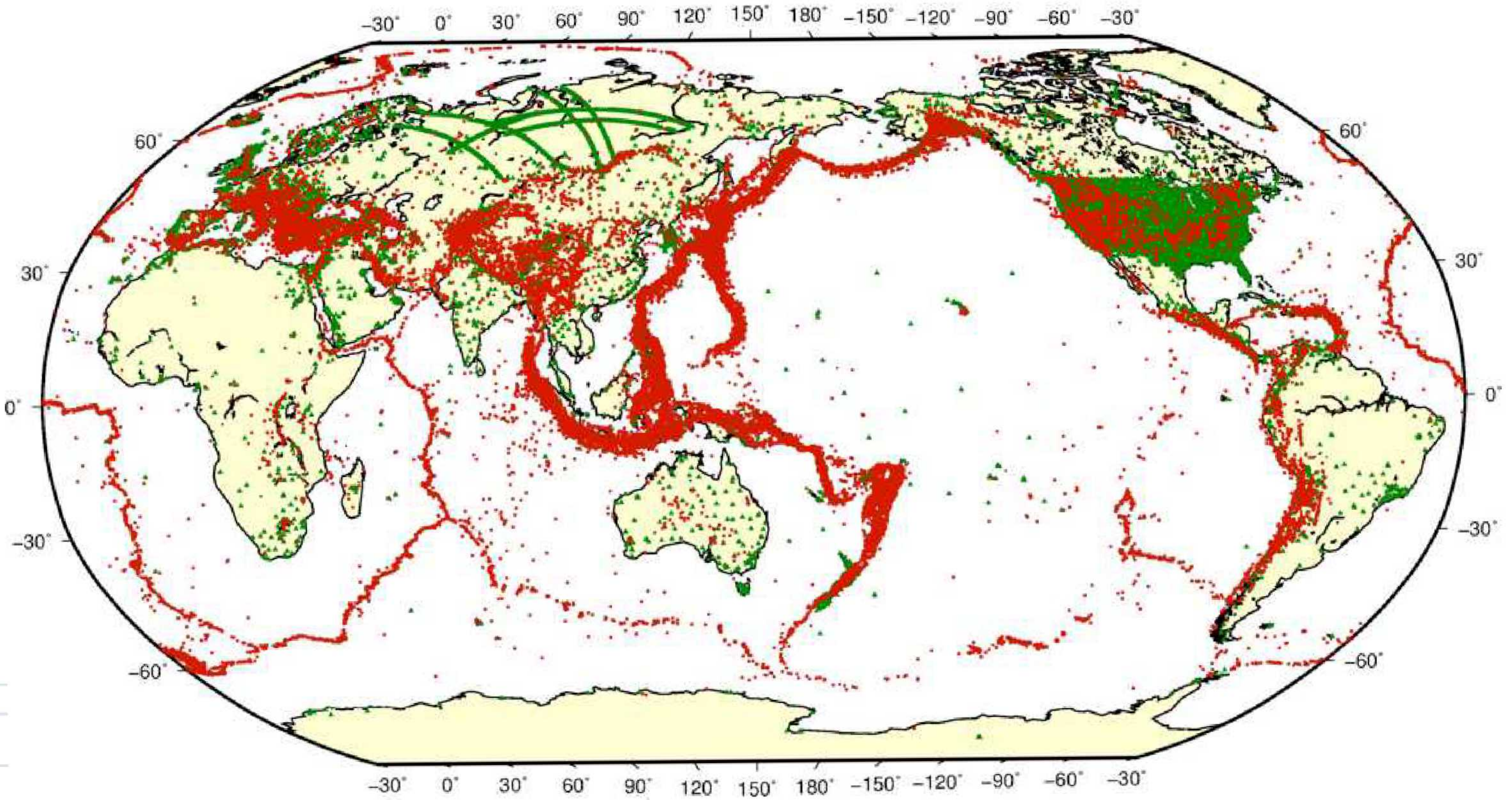


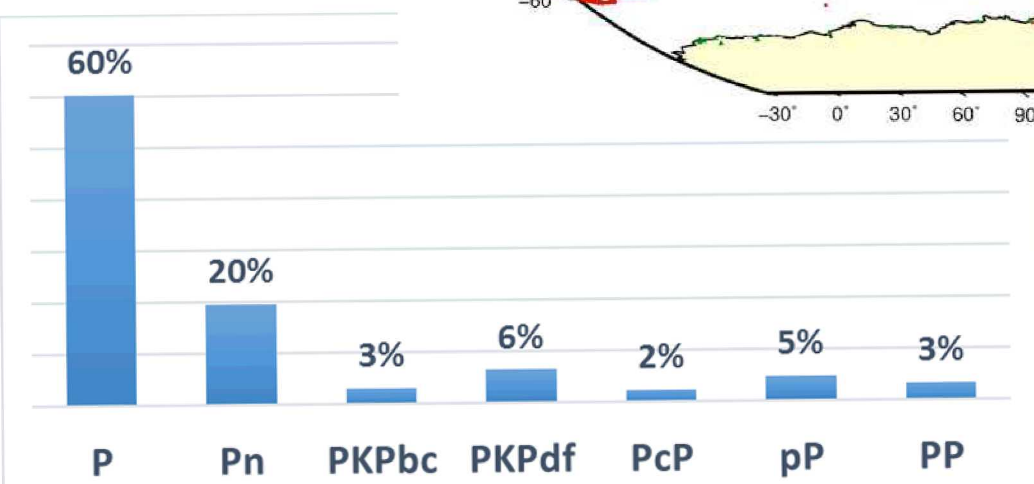
Tomography Data

117K events

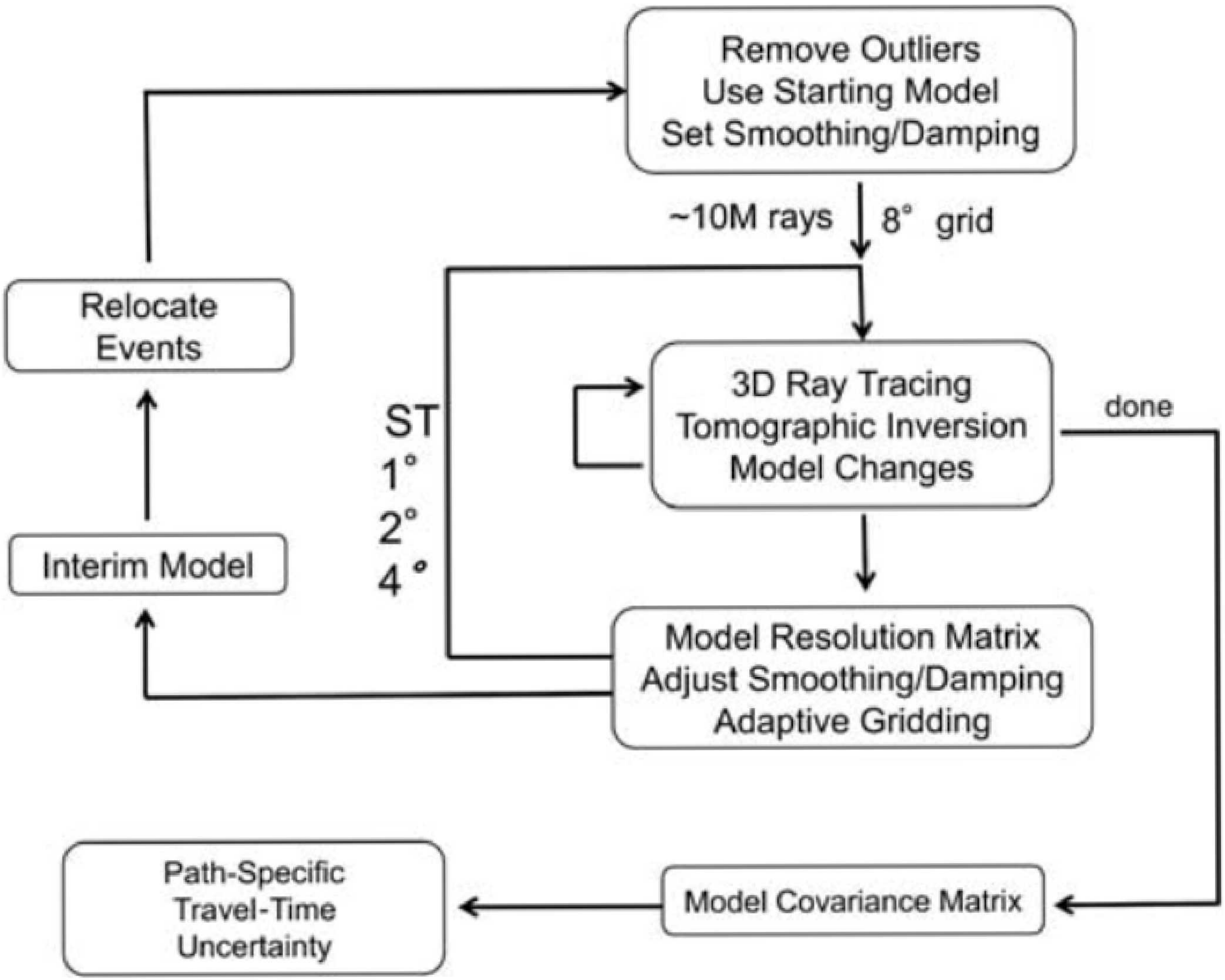
12K stations

12M rays





Tomographic Procedure



LSQR algorithm of Paige and Saunders (1982)

Travel Time Prediction Uncertainty

The standard least squares tomography solution seismic slowness, s, is formulated given an m x n set of non-linear travel time path length weights, $A(s)$; a vector of n associated path residuals, d; an n x n Bayesian inferred prior model covariance matrix, C_m. The Bayesian prior model parameters are used to constrain the solution in model regions possessing little or no data. This formulation can be written as

$$\begin{bmatrix} C_d^{-1/2} A(s_k) \\ \alpha C_m^{-1/2} \end{bmatrix} \Delta s^{k+1} = \begin{bmatrix} C_d^{-1/2}\left(d - A(s_k)s_k\right) \\ 0 \end{bmatrix} \qquad s^{k+1} = \Delta s^{k+1} + s^k$$

Where C_d are the data variances associated with the travel time path weights, α is a damping parameter applied to ensure solution stability, and the non-linear solution is updated in an iterative manner (k) until convergence is obtained $(\Delta s \approx 0)$. Applying standard solution techniques, the posterior model covariance, $\widetilde{C}_m$, and the model resolution, R_m, can be discovered and written as

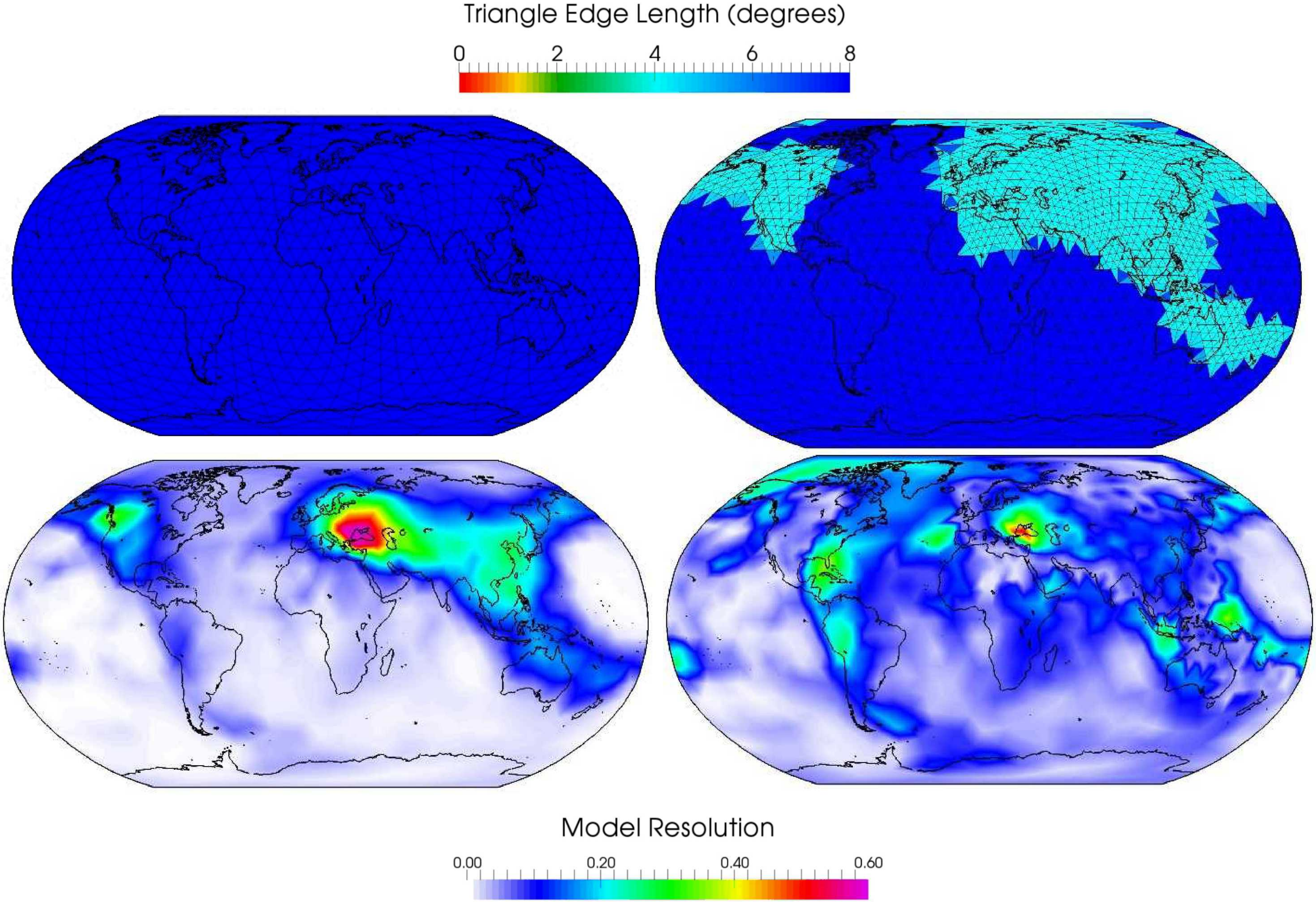
$$\widetilde{C}_m = \left[A^T C_d^{-1} A + C_m^{-1}\right]^{-1} \qquad R_m = \widetilde{C}_m A^T C_d^{-1} A = I - \widetilde{C}_m C_m^{-1}$$

Given these definitions we can formulate the travel time and associated uncertainty of an arbitrary ray path, p, given its grid node vector of path length weights ($W_p = <w_{pj}>$) as

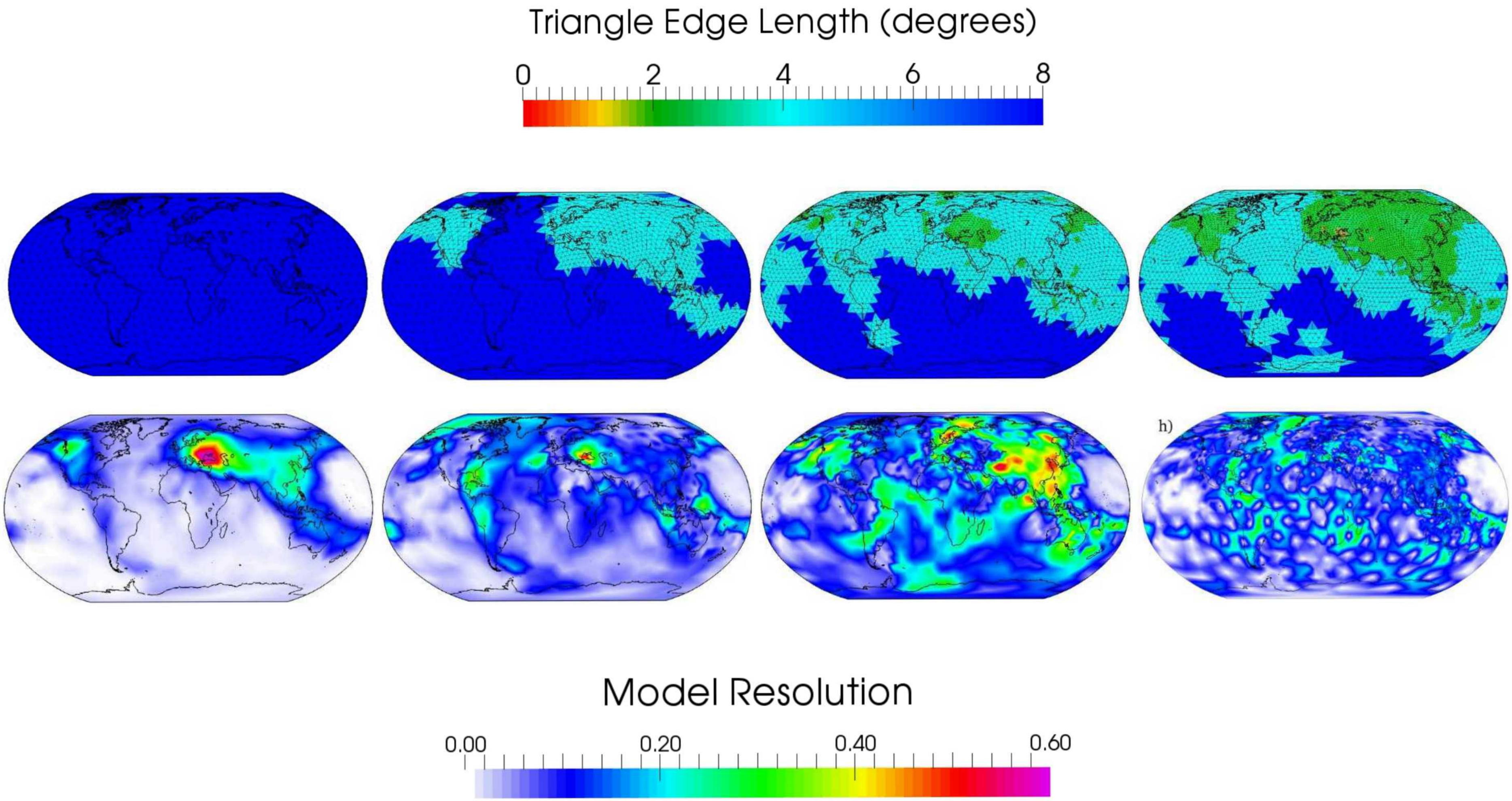
$$\widetilde{t}_p = \sum_{j=0} w_{pj} \widetilde{s}_j \pm \widetilde{\sigma}_p \qquad \widetilde{\sigma}_p = \sqrt{W(\widetilde{s}_m)\widetilde{C}_m W^T(\widetilde{s}_m) + W(s_m) C_m W^T(s_m)}$$

Here $W(\widetilde{s}_m)$ imply weights for nodes along the path p that lie in regions of the posterior model (the mantle), while $W(s_m)$ define weights for nodes along the path that lie in prior model regions for which slowness updates were not computed (the crust).

Grid and Model Resolution

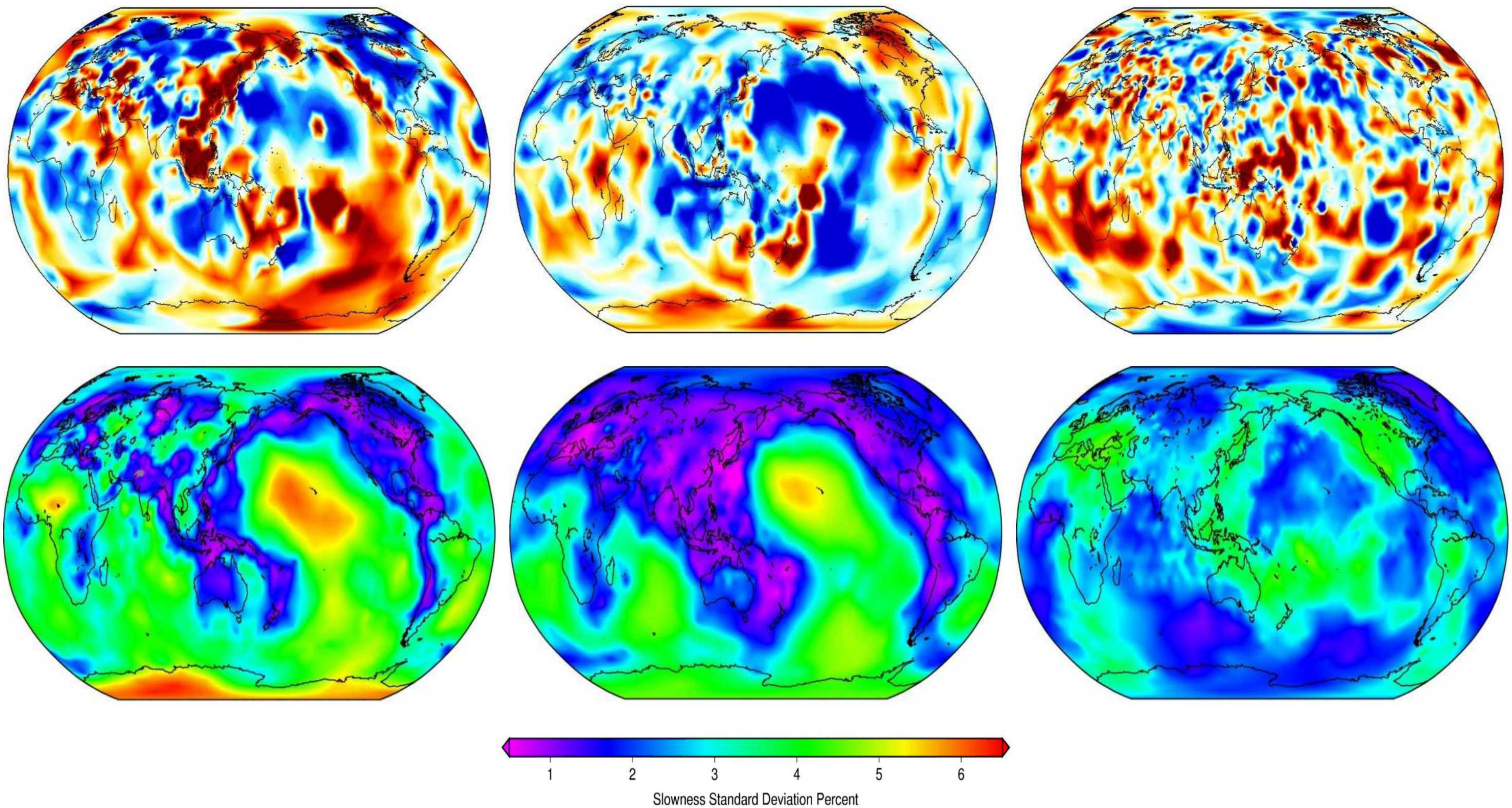


Grid and Model Resolution

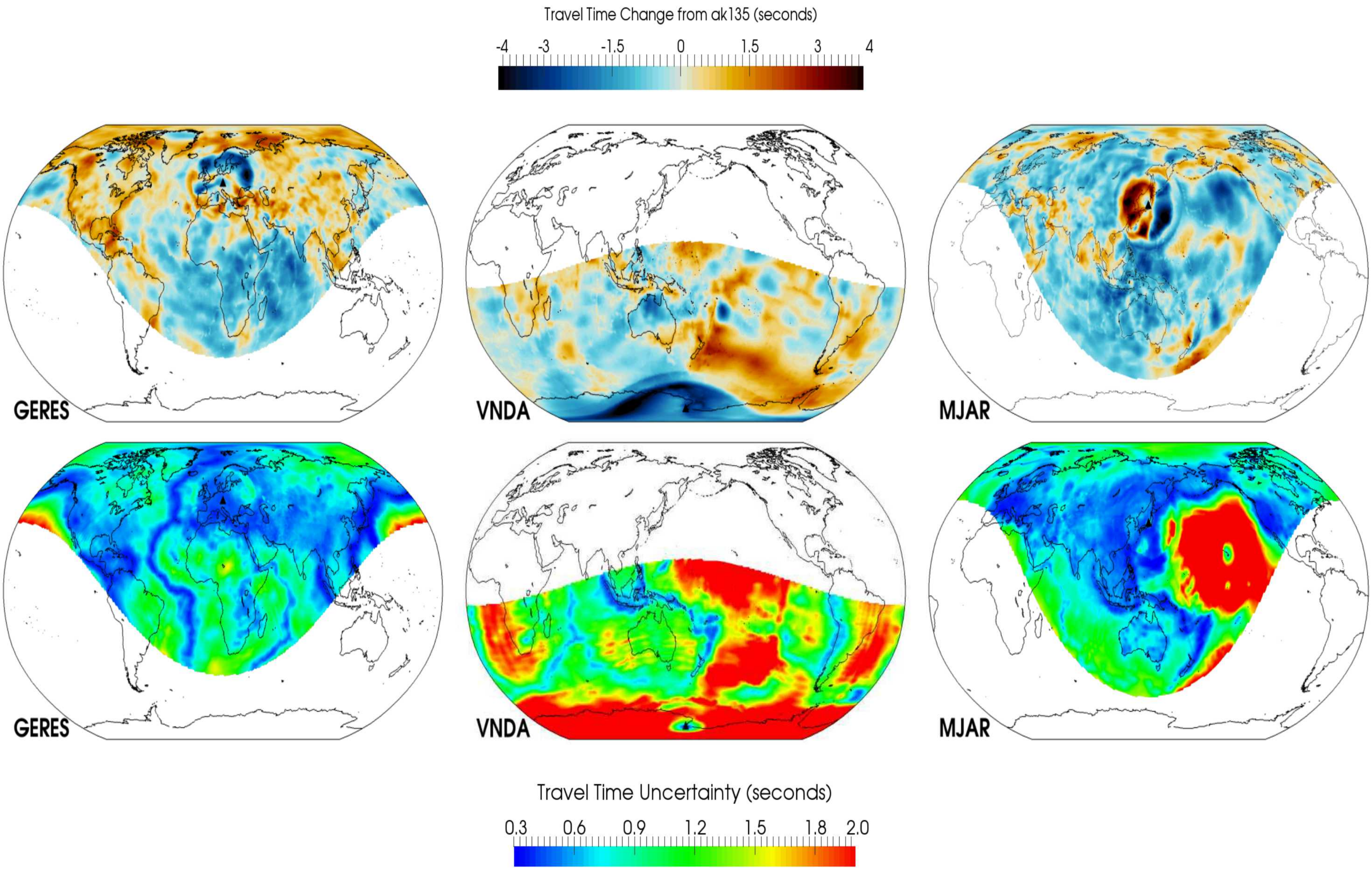


Mantle Slowness and Slowness Uncertainty

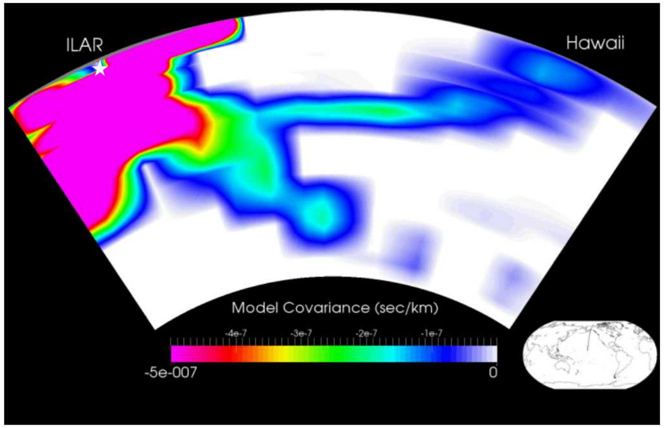
100 km ± 3% | 500 km ± 2% | 2500 km ± 1%

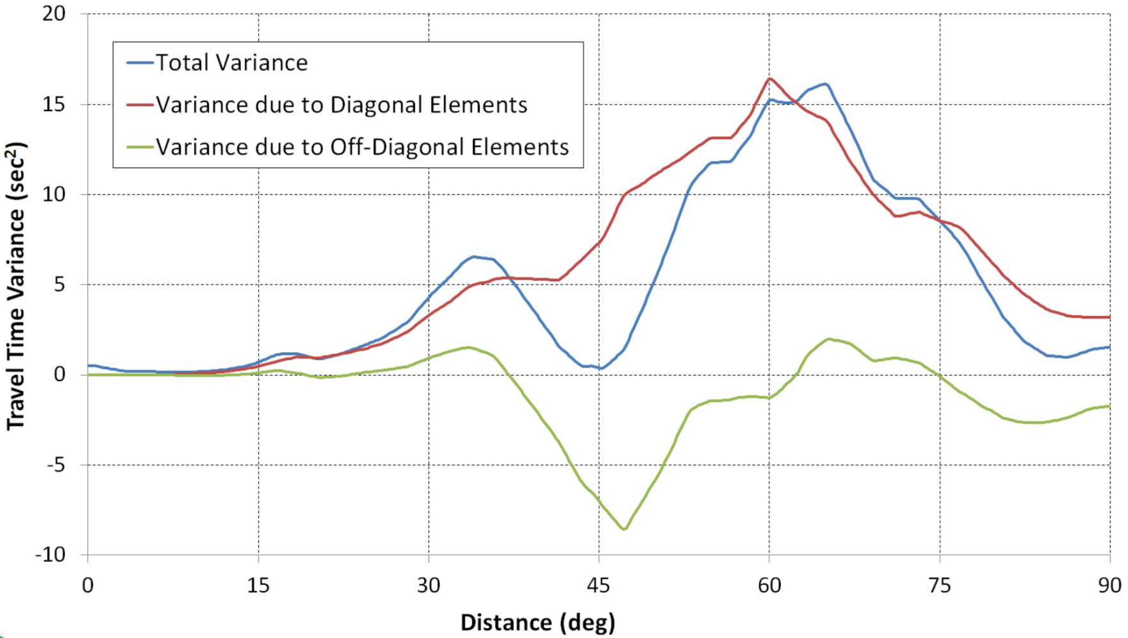


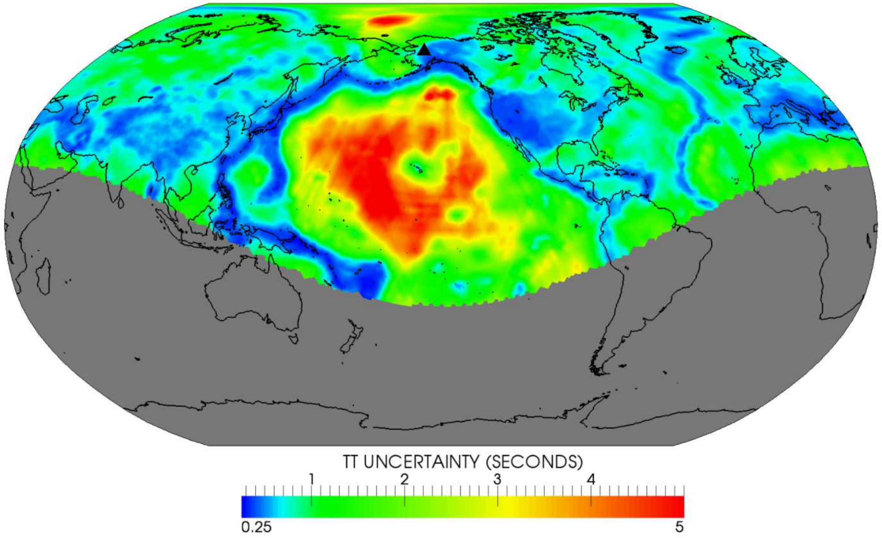
Travel Time Prediction and Uncertainty



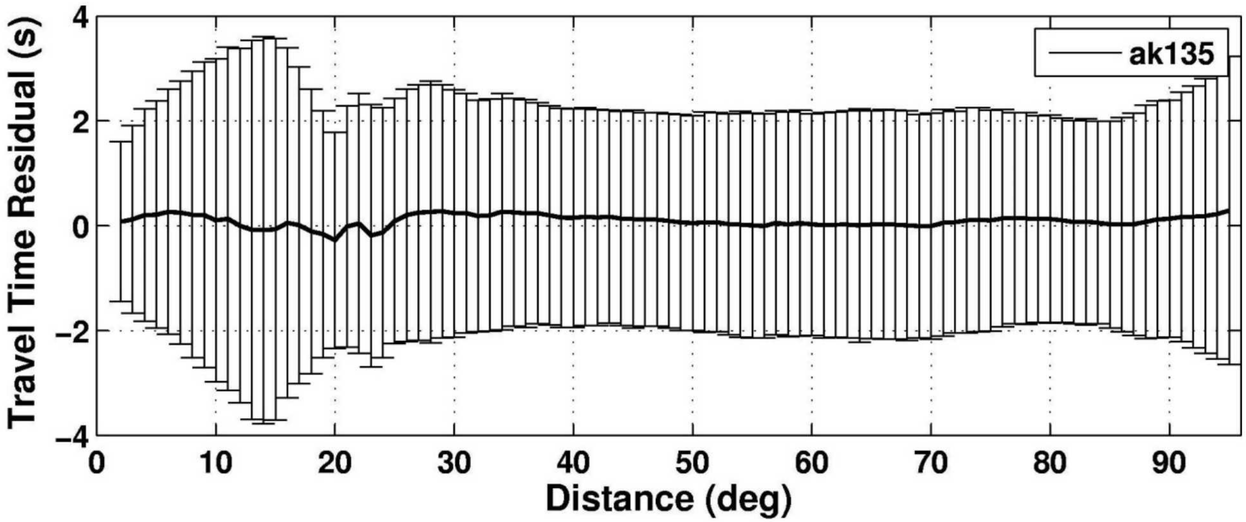
Significance of Off-Diagonal Terms

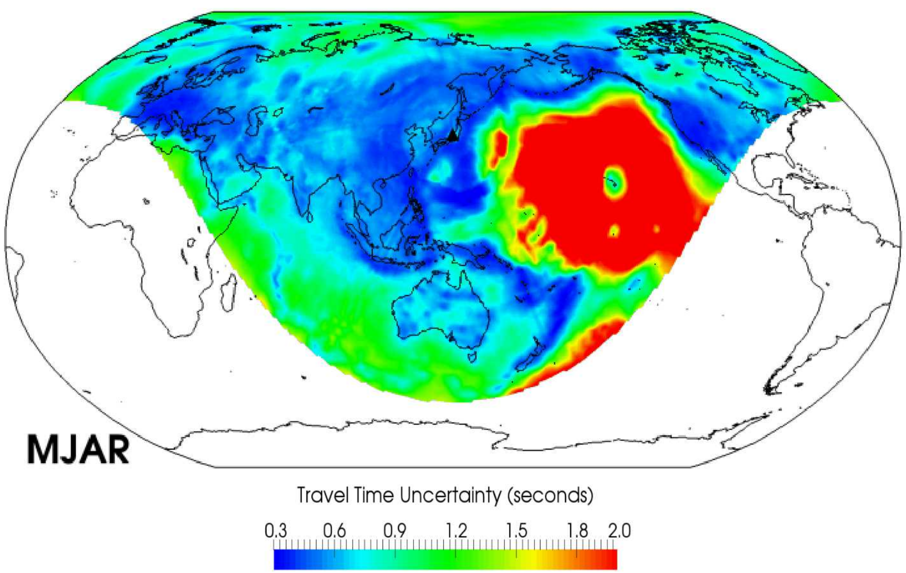


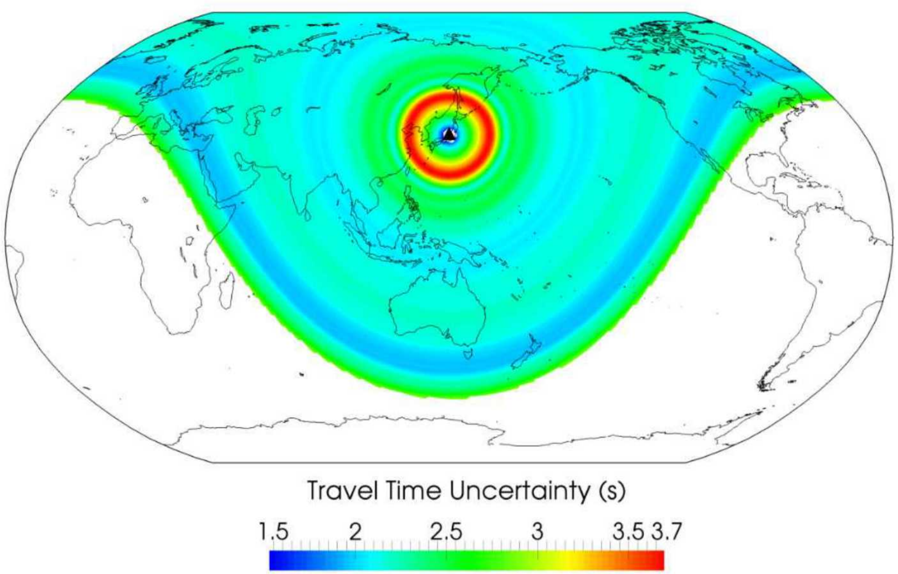




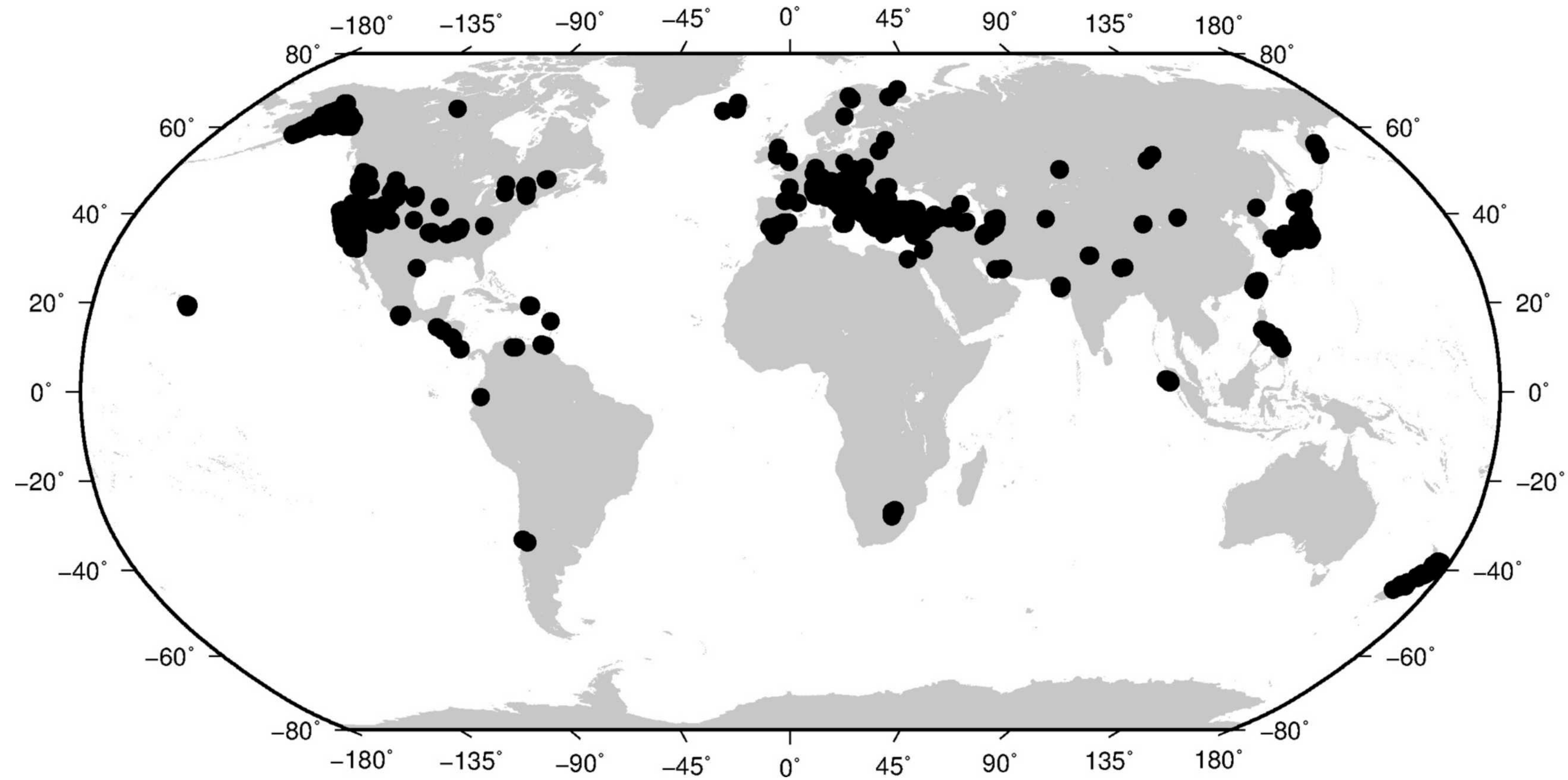
Comparison with Standard Uncertainty

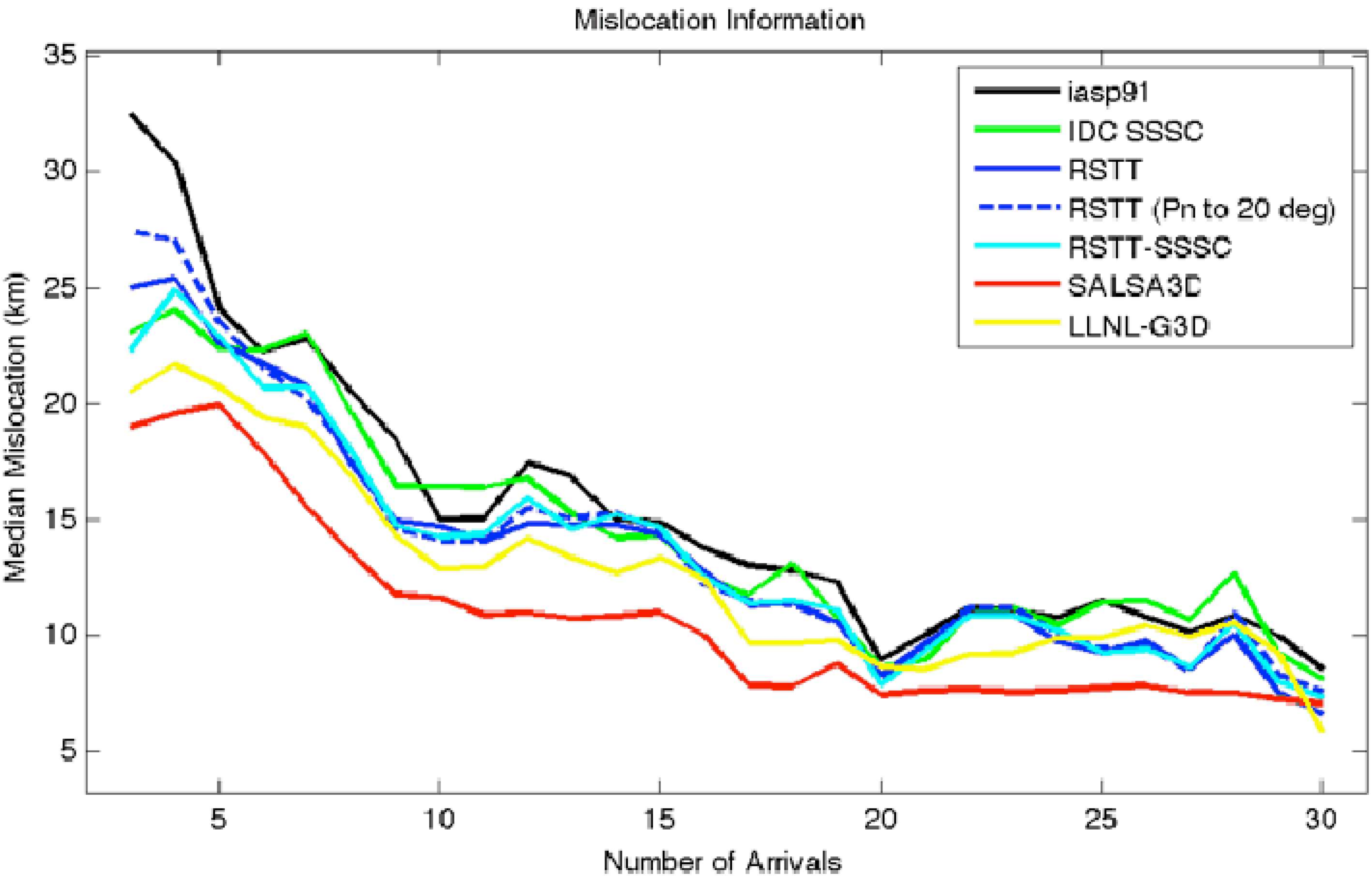






Seismic Events Used for Validation

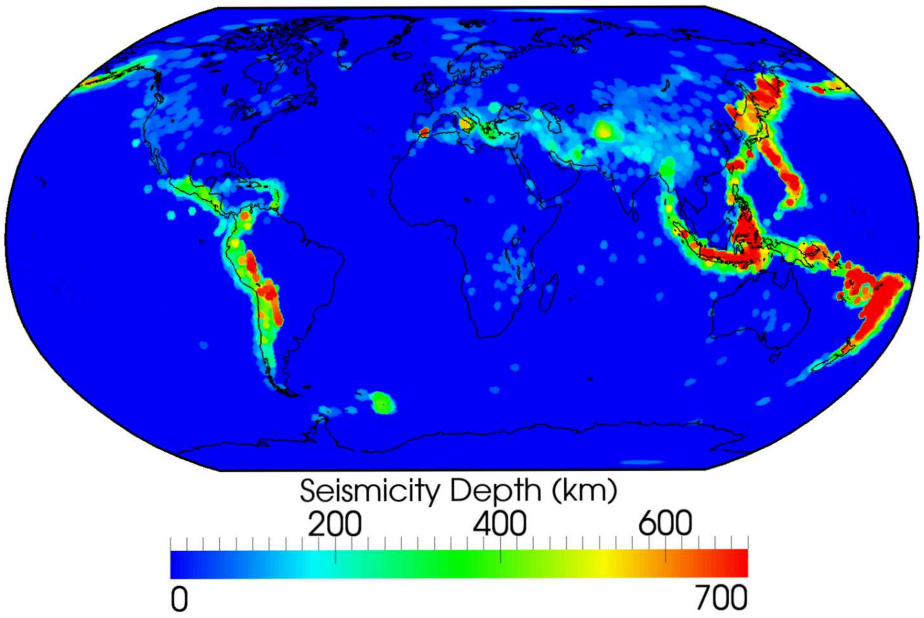


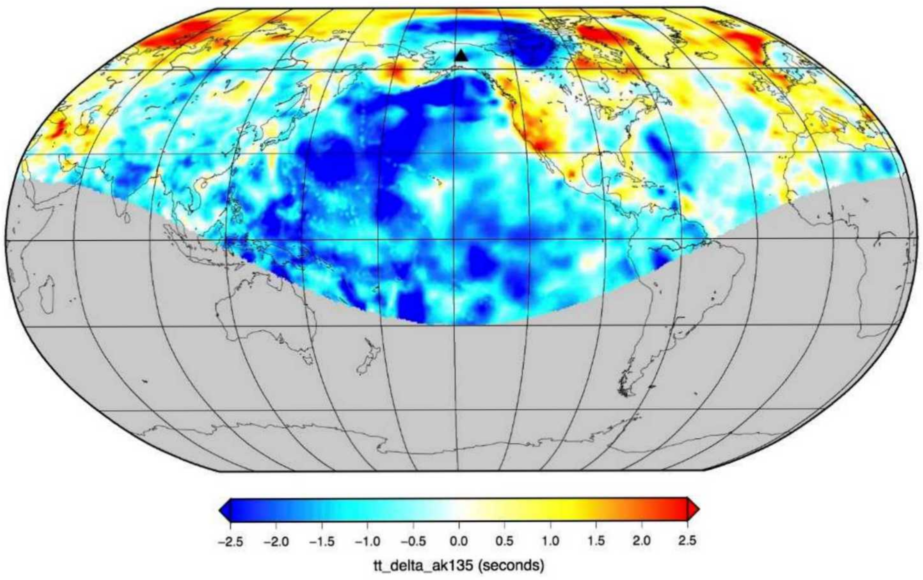


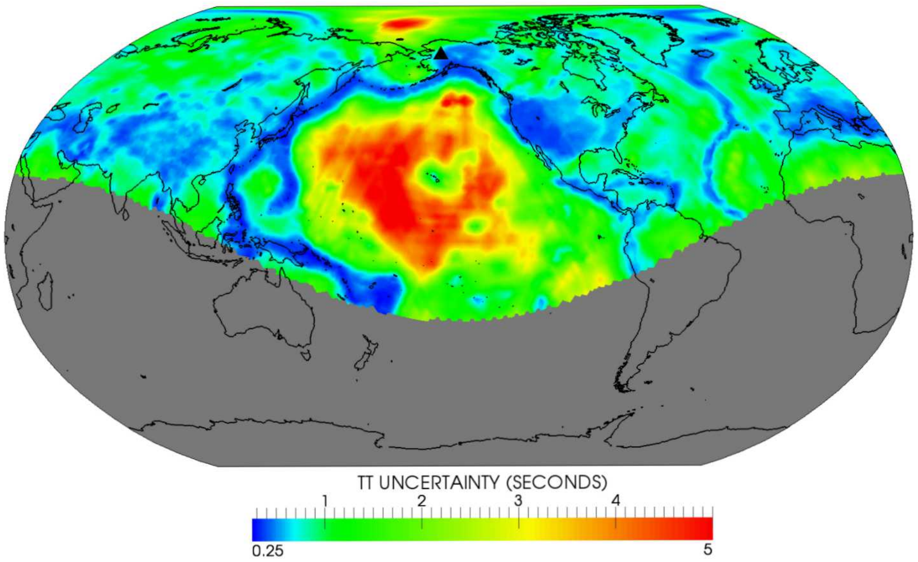
Mislocation Information
Median Mislocation (km)
Number of Arrivals
35
30
25
20
15
10
5
5
10
15
20
25
30
iasp91
IDC SSSC
RSTT
RSTT (Pn to 20 deg)
RSTT-SSSC
SALSA3D
LLNL-G3D

GeoTess

- Station-phase specific travel time difference relative to ak135.
- Path-dependent travel time prediction uncertainty (model error).
- First-P lookup tables for the IMS primary and auxiliary network requires about 3GB of RAM.







Summary

- We have developed a global 3D model of the seismic wave speed distribution in the Earth.
- We successfully computed the model covariance matrix for our model which allows us to calculate path-dependent travel time uncertainty estimates.
- The model significantly improves the accuracy and precision and seismic event locations.
- We have developed 3D travel time lookup tables for the IMS network to mitigate performance issues related to the use of 3D models in operational systems
- Our grid management software GeoTess has been released as open source software and can be accessed at www.sandia.gov/geotess

Future Work

- For SALSA3D, we did not invert for the crustal model. We are planning on creating a local crustal velocity model in near proximity of the state of Utah using arrivals provided by the UUSS in an effort to assess the applicability of our tomography approach to crustal tomography.
- We will extend the tomography campaign to include surface wave data for a better sampling of the crust and uppermost mantle.
- Similar to SALSA3D, we intend to develop a 3D velocity model for *S*-wave travel time prediction.
- We intend to develop velocity/attenuation models of the Earth’s crust and mantle based on full waveform tomography methods.

SALSA3D - References

Ballard, S., J. R. Hipp, M. L. Begnaud, C. J. Young, A. V. Encarnacao, E. P. Chael, W. S. Phillips (2016) SALSA3D – A Tomographic Model of Compressional Wave Slowness in the Earth's Mantle For Improved Travel Time Prediction and Travel Time Prediction Uncertainty, Bulletin of the Seismological Society of America, Vol. 106, No. 6, pp. 2900-2916, December 2016, doi: 10.1785/0120150271.

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Ballard, S., J. R. Hipp and C. J. Young (2009). Efficient and Accurate Calculation of Ray Theory Seismic Travel Time through Variable Resolution 3D Earth Models, Seismological Research Letters v 80, 6 doi: 10.1785/gssrl.80.6.989.