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SALSA3D

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

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

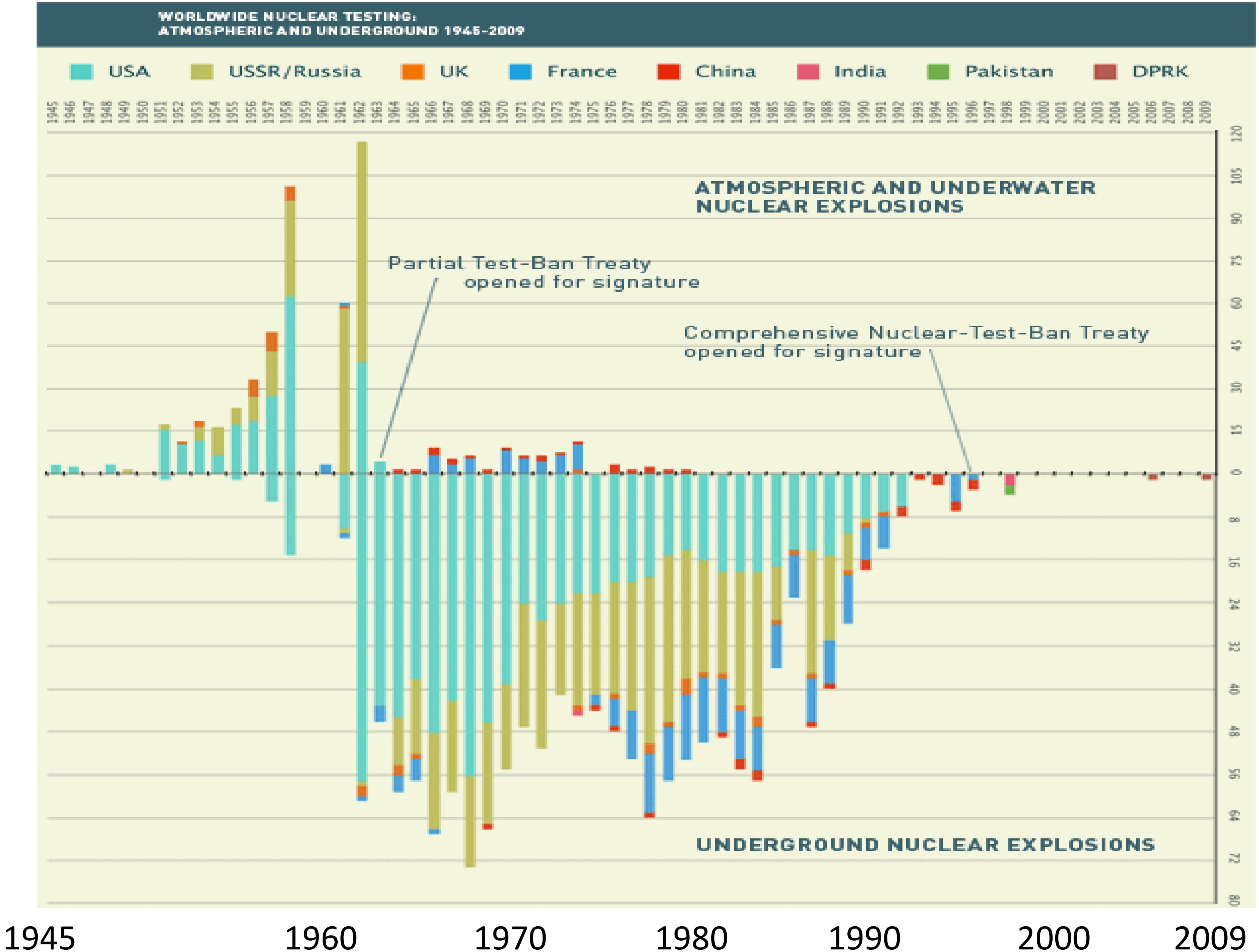


Figure from CTBTO website www.ctbto.org

CTBT International Monitoring System

Seismic Tomography

The standard least squares tomography solution for p-wave slowness, s, is formulated given an $m \times n$ set of non-linear travel time path length weights, $A(s)$; a vector of n associated path residuals, d; an $n \times n$ 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

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

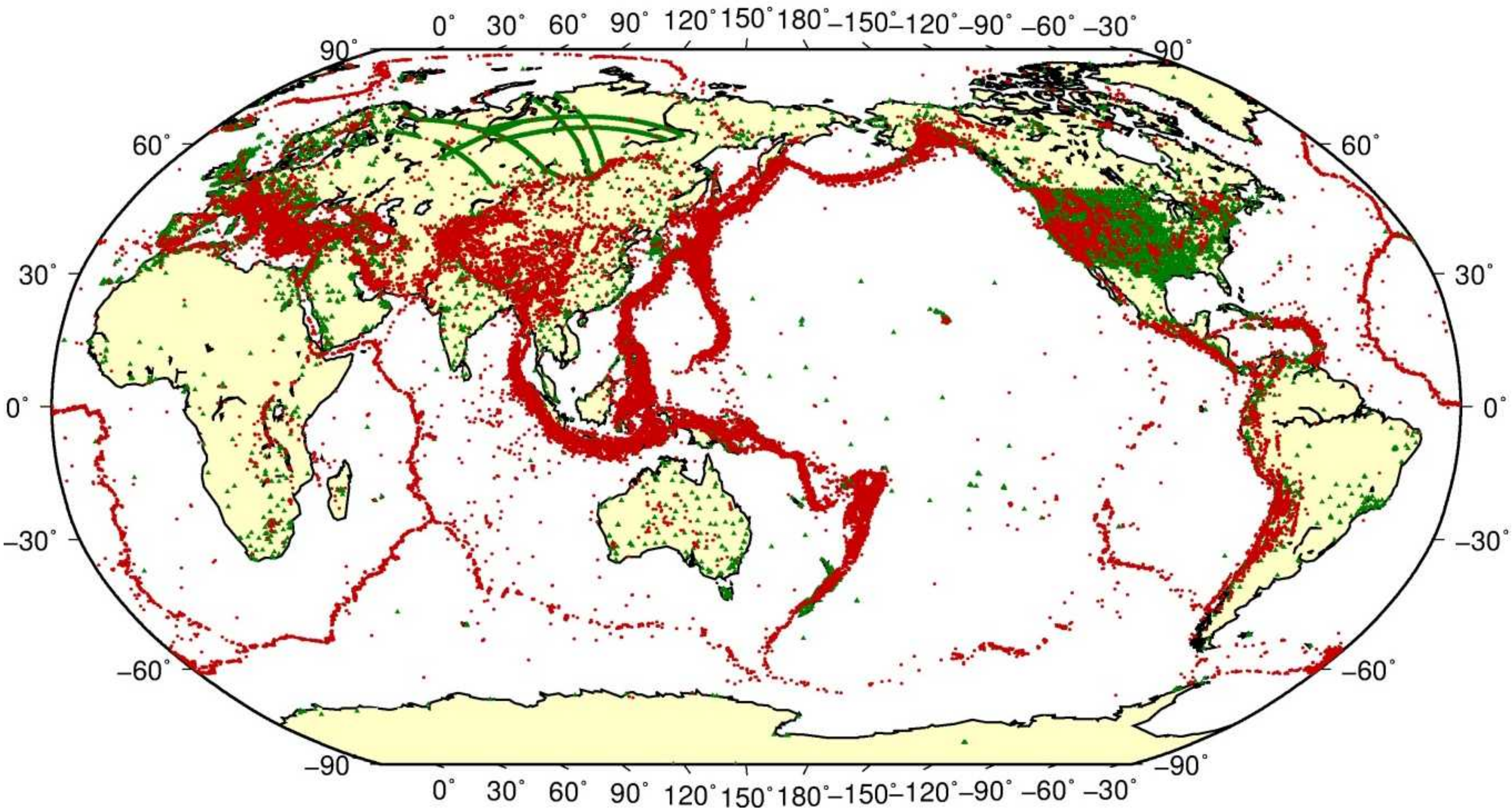
Given these definitions we can formulate the travel time and associated uncertainty of an arbitrary ray path, p, given its grid node vector of path length weights ($W_p = \langle w_{pj} \rangle$) as

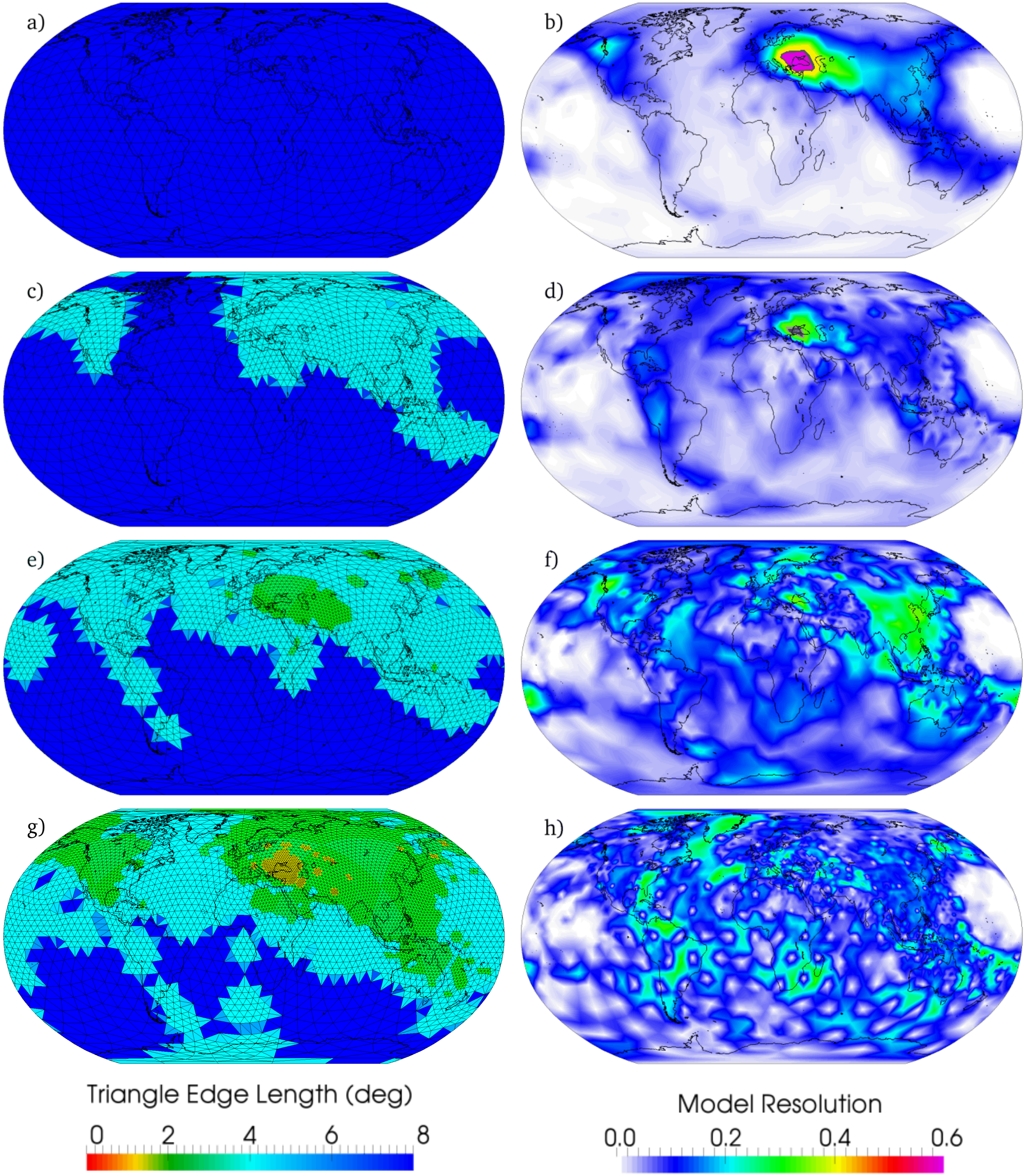
$$\widetilde{t}_p = \sum_{j=0} w_{pj} \widetilde{s}_j \pm \widetilde{\sigma}_p \qquad \widetilde{\sigma}_p = \sqrt{W(\widetilde{s}_m) \widetilde{C}_m W^T(\widetilde{s}_m) + W(s_m) C_m W^T(s_m)}$$

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).

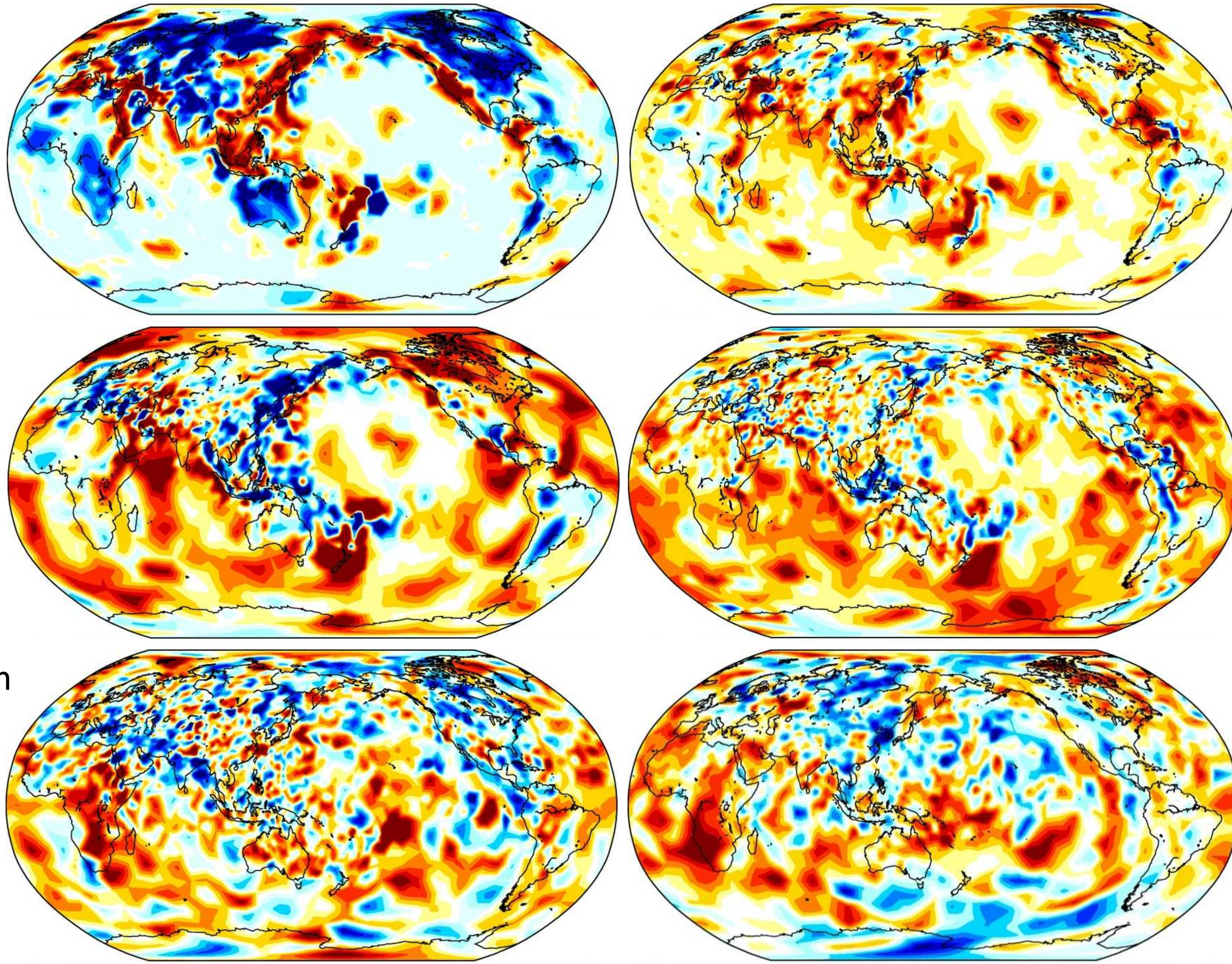
Tomography Data

117K events | 12K stations | 12M ray paths




a)
b)
c)
d)
e)
f)
g)
h)
Triangle Edge Length (deg)
0
2
4
6
8
Model Resolution
0.0
0.2
0.4
0.6

Mantle Slowness



100 km
± 3%

300 km
± 3%

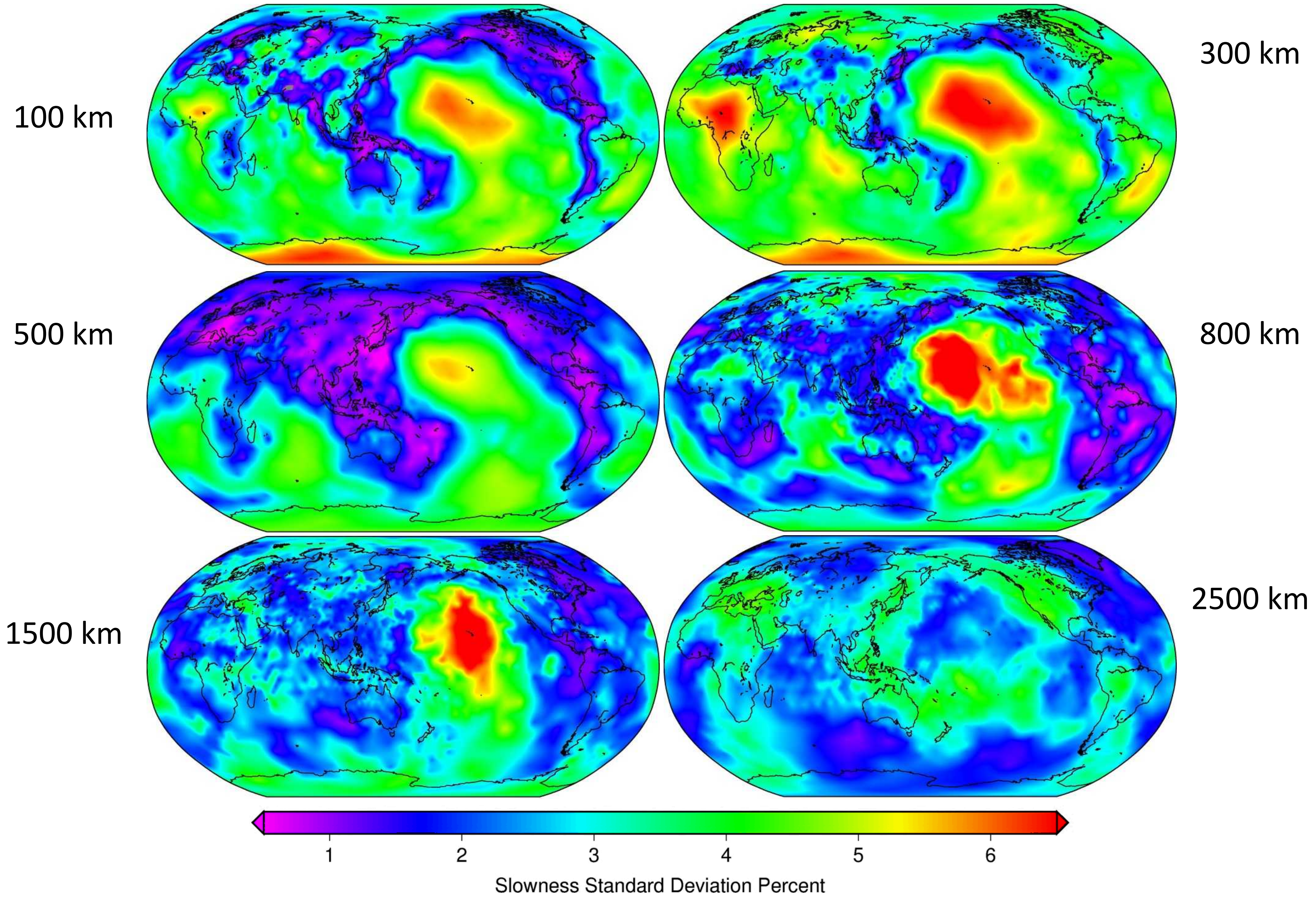
500 km
± 1.5%

800 km
± 1.5%

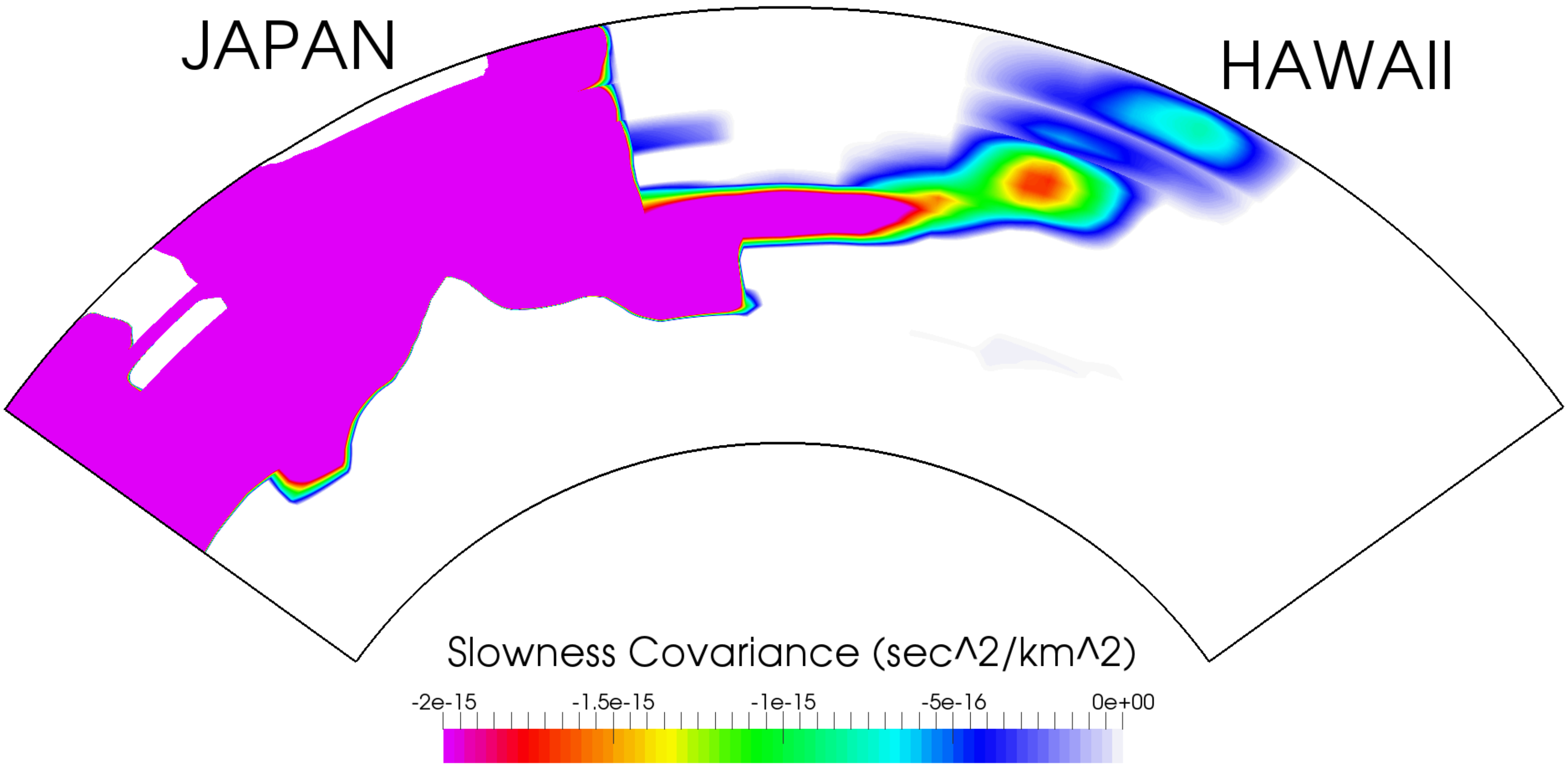
1500 km
± .8%

2500 km
± .8%

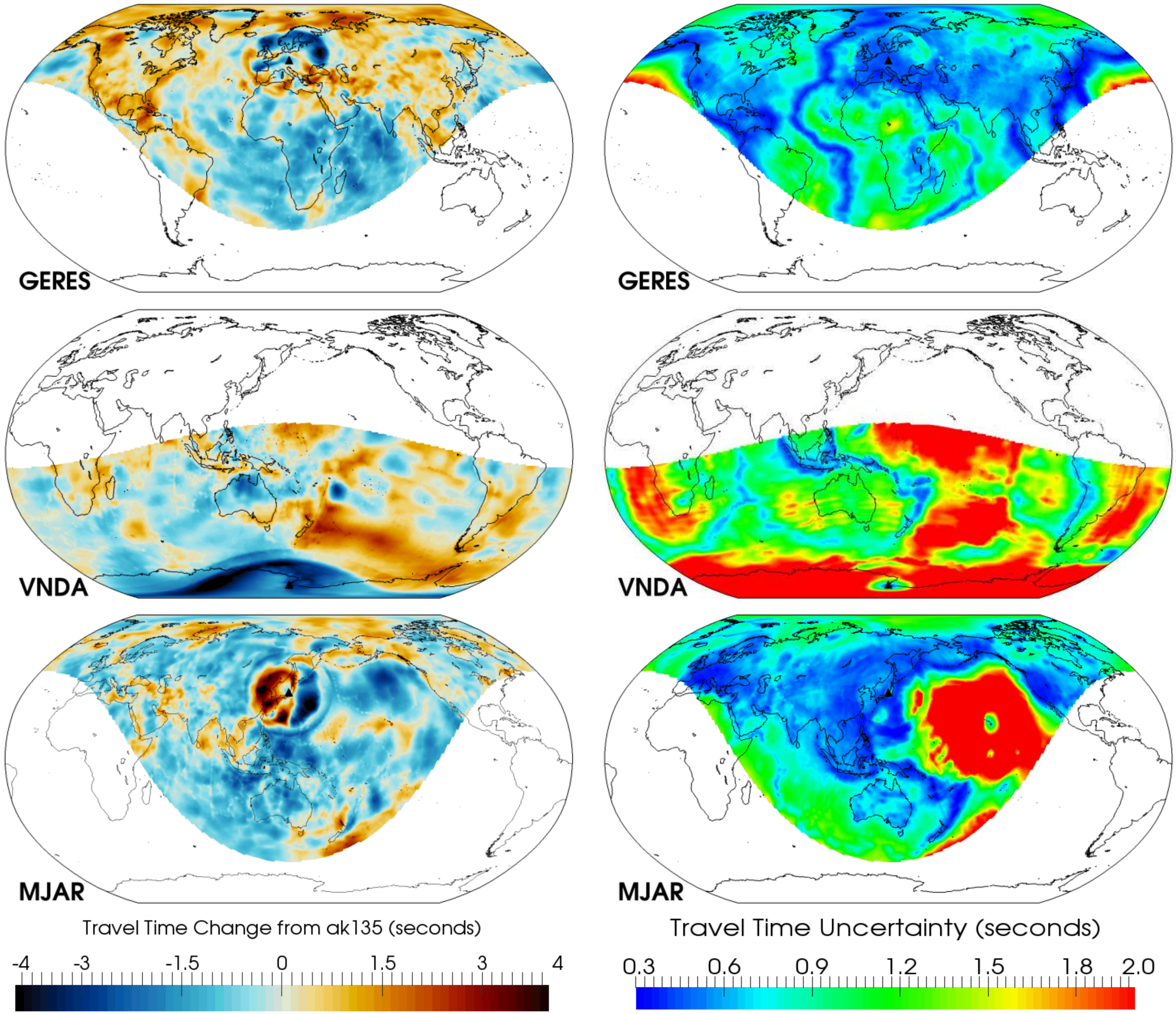
Uncertainty of Mantle Slowness



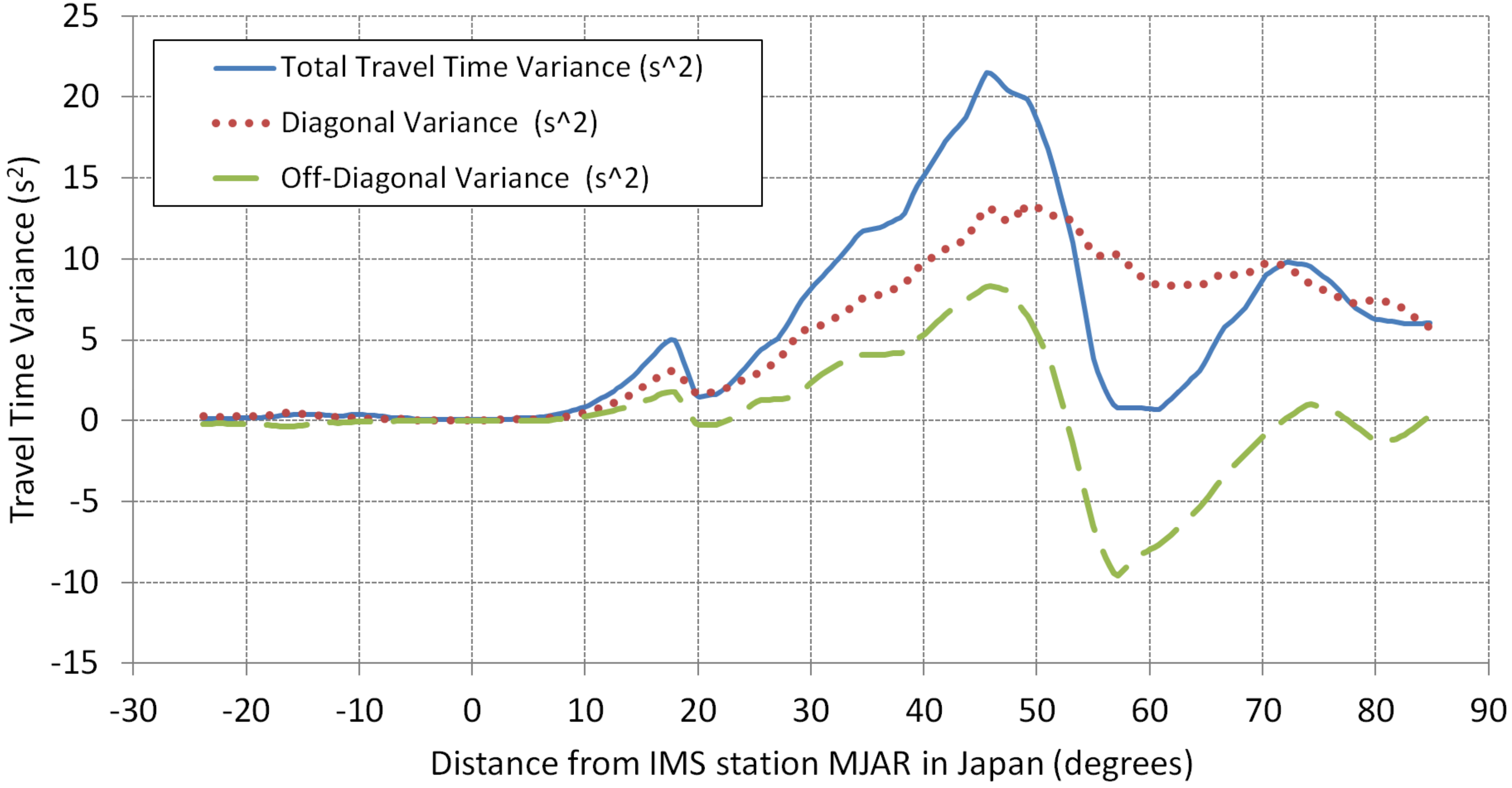
Importance of Model Covariance



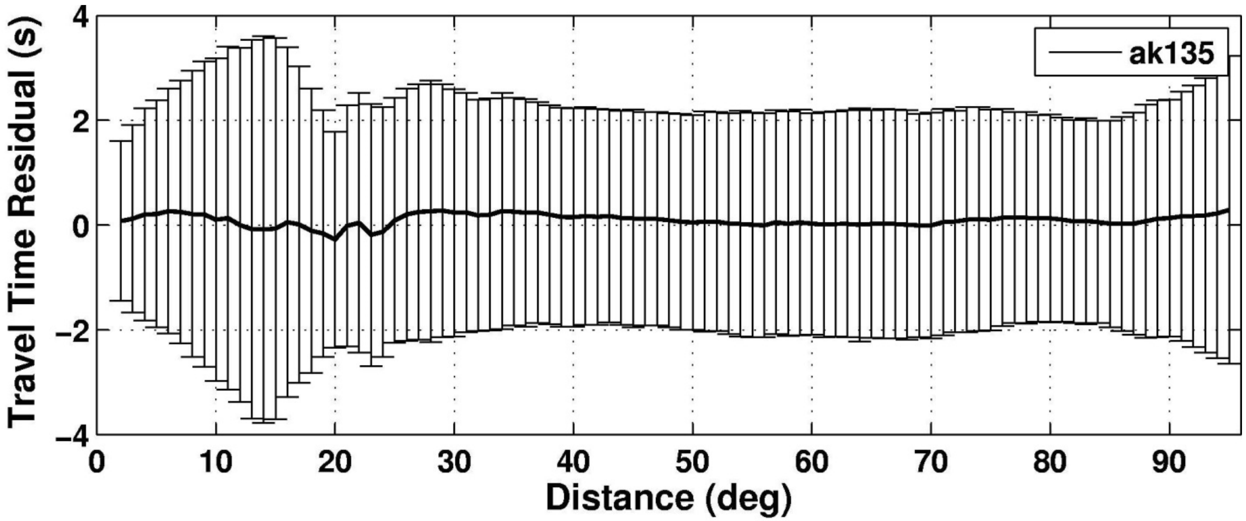
Travel Time Prediction and Uncertainty

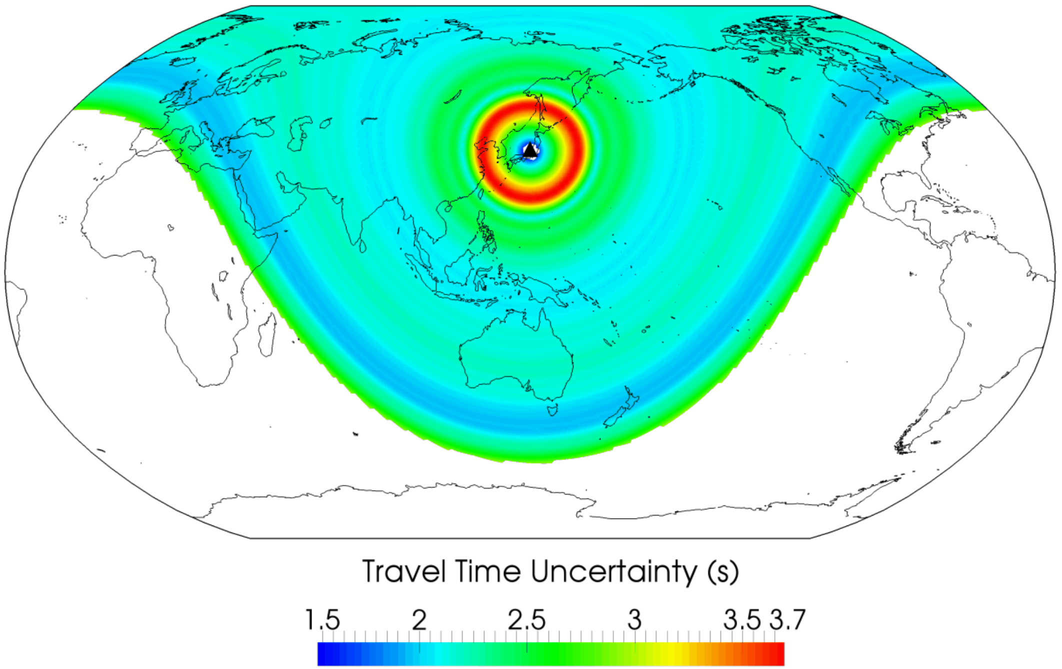


Importance of Model Covariance

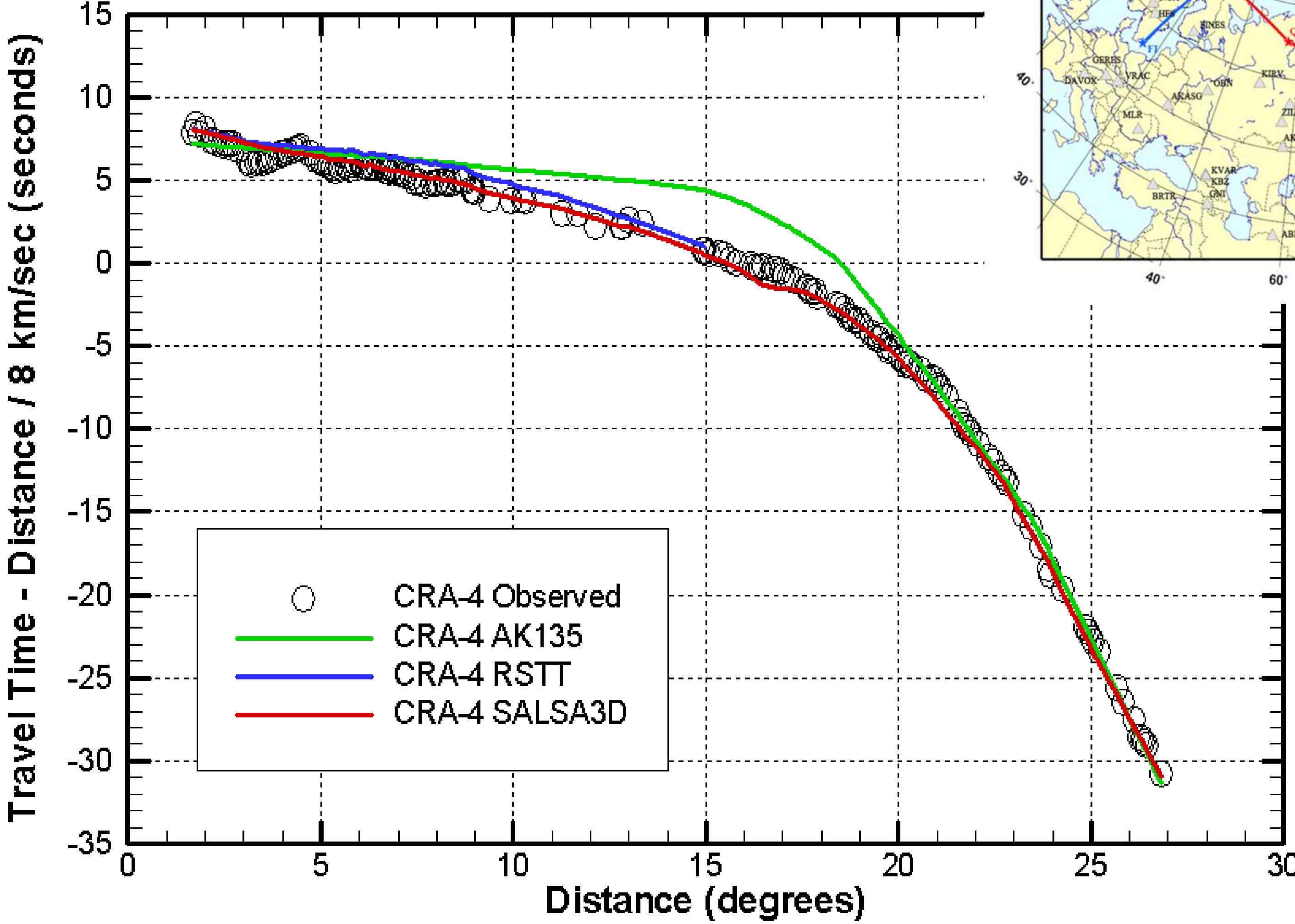


Comparison with Standard Uncertainty

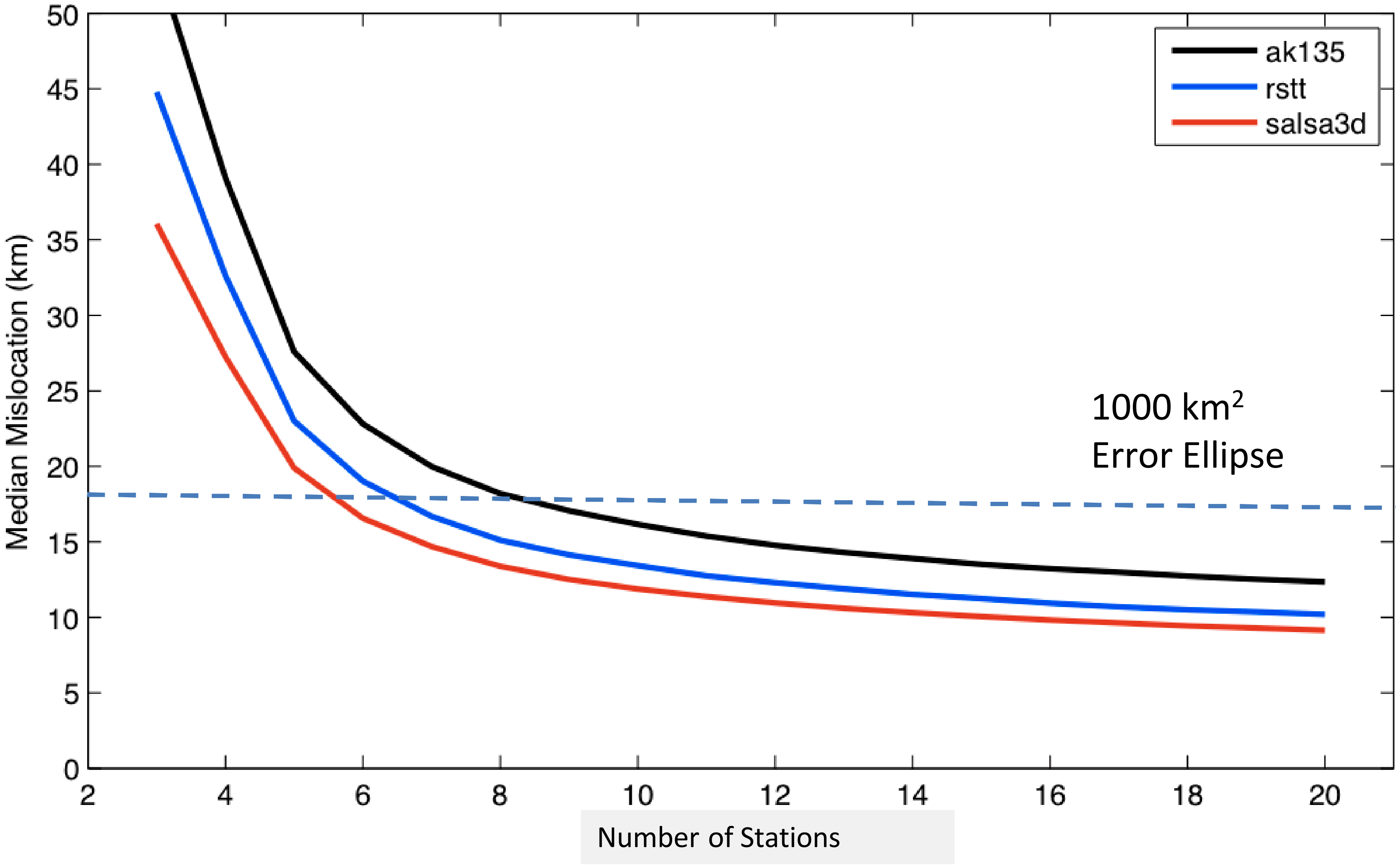




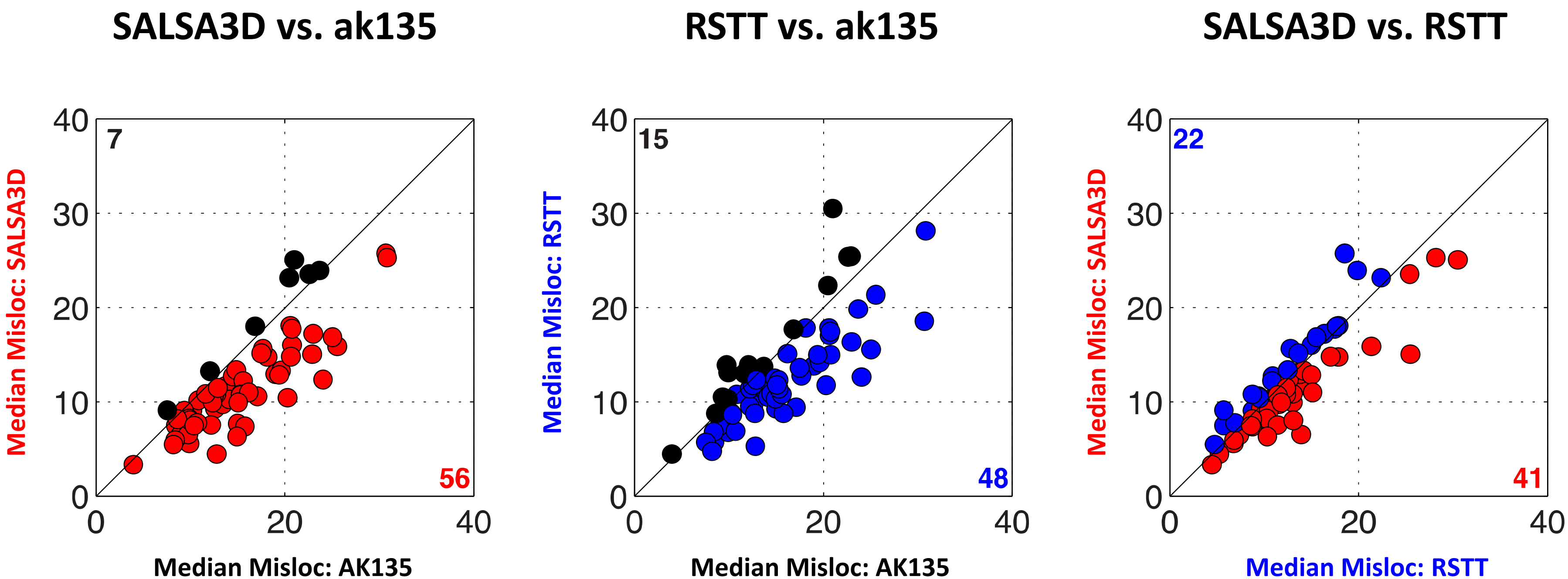
Deep Seismic Sounding (DSS) Lines



Mislocation vs. Number of Stations



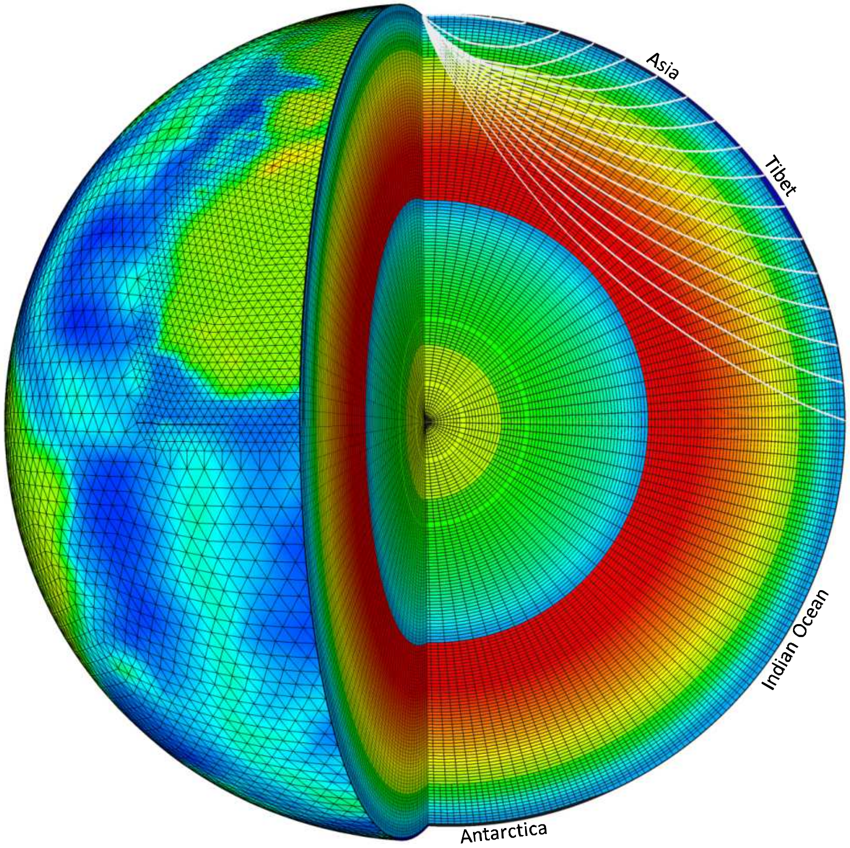
Event Mislocation Comparisons



GeoTess

A model parameterization and software support system that implements the construction, population, storage and interrogation of data stored in 3D Earth models.

- Grid based on triangular tessellations
- Variable resolution in both geographic and radial dimensions
- Supports internal radial discontinuities with variable topography.
- Wide variety of data types for storage of information at grid nodes
- Linear and natural neighbor interpolation of values
- Open source software in C, C++ and Java
- Compiled for Linux, Mac, Windows and SunOS.
- Software available at www.sandia.gov/geotess



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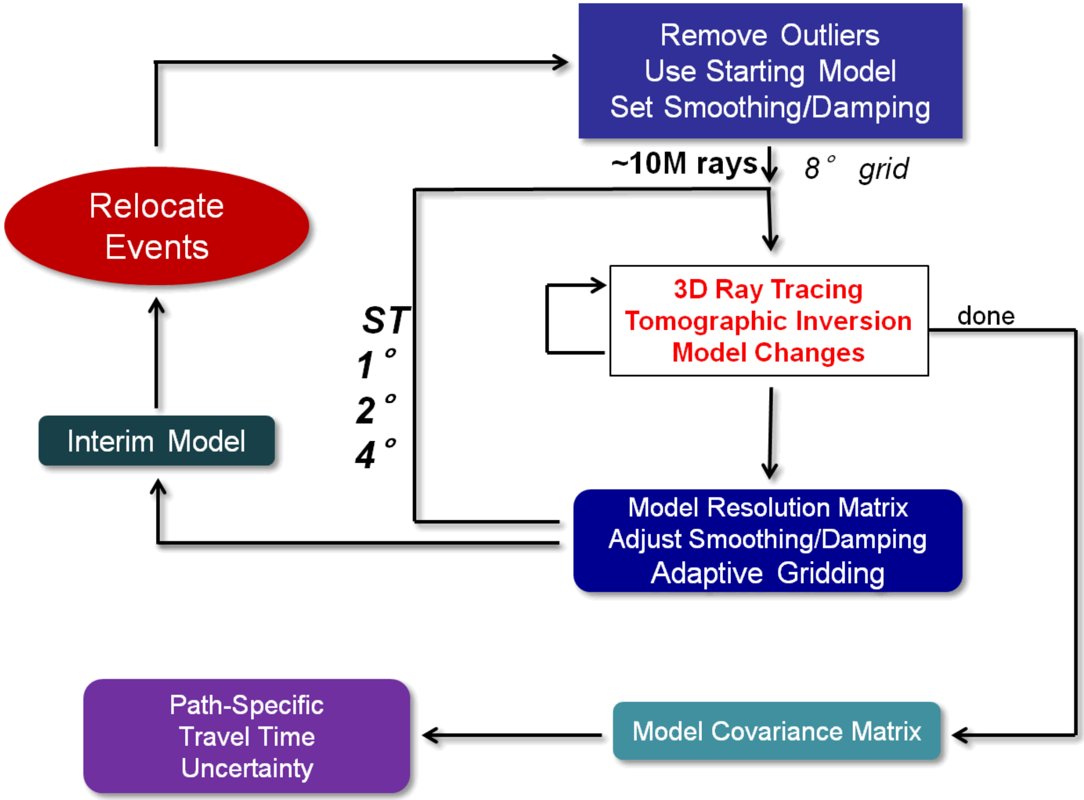
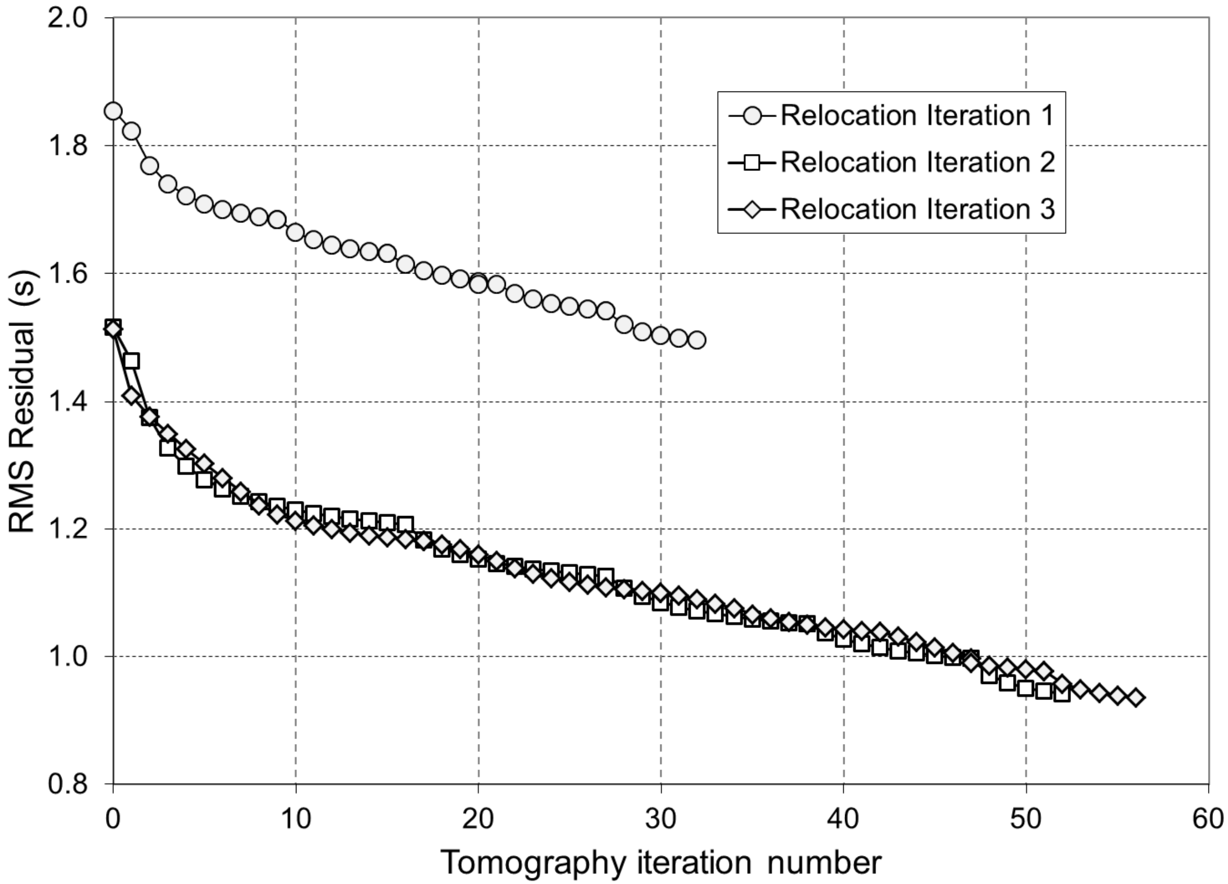
NNSA National Nuclear Security Administration

Summary

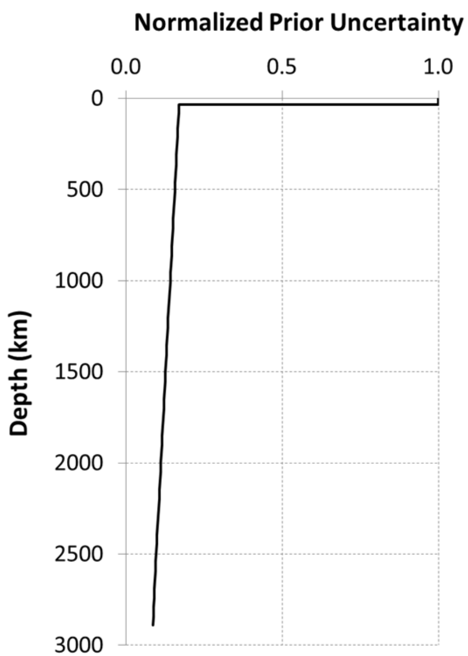
- We have developed a global 3D model of the compressional wave speed distribution in the Earth’s crust and mantle.
- We successfully computed the model covariance matrix for our model which allows us to calculate path-dependent travel time uncertainty estimates.
- The model significantly improves the 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 has been released as open source software and can be accessed at www.sandia.gov/geotess

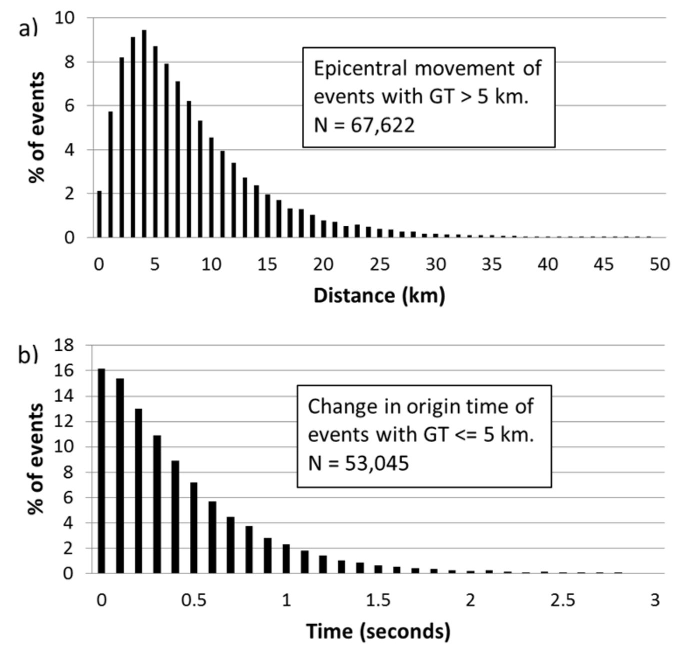
END


Remove Outliers
Use Starting Model
Set Smoothing/Damping
~10M rays
8° grid
Relocate Events
ST
1°
2°
4°
3D Ray Tracing
Tomographic Inversion
Model Changes
done
Interim Model
Model Resolution Matrix
Adjust Smoothing/Damping
Adaptive Gridding
Path-Specific Travel Time Uncertainty
Model Covariance Matrix



Relocation Iteration 1
Relocation Iteration 2
Relocation Iteration 3
RMS Residual (s)
Tomography iteration number
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0
10
20
30
40
50
60


Normalized Prior Uncertainty
0.0
0.5
1.0
0
500
1000
1500
2000
2500
3000
Depth (km)


a)
Epicentral movement of events with GT > 5 km.
N = 67,622
% of events
Distance (km)
0 5 10 15 20 25 30 35 40 45 50
0 2 4 6 8 10
b)
Change in origin time of events with GT <= 5 km.
N = 53,045
% of events
Time (seconds)
0 0.5 1 1.5 2 2.5 3
0 2 4 6 8 10 12 14 16 18