Regional Seismic Travel Time (RSTT) Modeling Technique

Science & Technology Conference, June 2011

Presented By Stephen C. Myers

S. C. Myers¹, M. Begnaud², S. Ballard³, A. Ramirez¹, S. Phillips², M. Pasyanos¹

¹Lawrence Livermore National Laboratory
²Los Alamos National Laboratory
³Sandia National Laboratories
Regional Data Can Degrade Location Accuracy

- Location of low-magnitude events may rely on 1 or more regional stations.
- Adding even 1 regional (Pn) arrival time tends to degrade location accuracy.

![Graph showing degradation in location error when 1 Pn is added](chart)

- Average number of phases used in REB (2008 to present) to locate events of varying magnitude:
  - mb=3.5
  - mb=4.0
  - mb=4.5
  - mb=5.0

Global data used to evaluate location accuracy
Regional Data Can Degrade Location Accuracy

- Location of low-magnitude events may rely on 1 or more regional stations.
- Adding even 1 regional (Pn) arrival time tends to degrade location accuracy.

Global data used to evaluate location accuracy
Regional Data Can Degrade Location Accuracy

- Location of low-magnitude events may rely on 1 or more regional stations.
- Adding even 1 regional (Pn) arrival time tends to degrade location accuracy.

Global data used to evaluate location accuracy

Degradation in location error when 1 Pn is added

Average number of phases used in REB (2008 to present) to locate events of varying magnitude

- $mb=3.5$
- $mb=4.0$
- $mb=4.5$
- $mb=5.0$

Number of P phases

Median Error Degradation (km)
Why Does Location Degrade When Regional Data Are Introduced?

- **Velocity heterogeneity** is strongest in the crust and upper mantle.
- **Regional seismic rays** travel entirely in the crust and upper mantle.
- **Travel-time prediction error** peaks at regional-distance.
RSTT Model Accounts for Crust and Upper-Mantle Heterogeneity

- 3-dimensional crust
- Laterally varying upper mantle

![Diagram showing a 3D model of the Earth's crust and upper mantle with labeled layers and features such as sedimentary basins, 7 crustal layers, variable-thickness crust, and linear gradient.](image-url)
RSTT Model Parameterization is Inherently Global

- Seamless global tessellation
- Most recent model is variable resolution

Multi-resolution enabled
Travel Time Calculation For Pn & Sn

- Approximation of travel time
  \[ TT = \sum_{i=1}^{N} d_i s_i + \alpha + \beta + \gamma \]

- Algebraic form enables \(~1\) msec (real time) computation.

- Accounts for diving rays in a velocity gradient
  (Zhao and Xie, 1993).

\[ \gamma = \frac{c^2 X_m^3}{24 V_0^4} \]

- \( d \): path increment immediately below crust/mantle boundary.
- \( s = 1/velocity \)
- \( \alpha \): source-side portion of ray.
- \( \beta \): receiver-side portion of ray.

Model cross section and representative Pn ray path
Why Mantle Velocity Gradient is Important?

Travel Time Predictions with and without a velocity gradient

Pn Travel Time
High-Quality Tomographic Data Set

- Reconciliation of global, regional, and local bulletins.
- Location accuracy assessed for each event based on network coverage (Bondar et al., 2004).
- Ground truth locations for explosions (e.g. Sultanov et al., 1999; Springer et al., 2002).
- Quality control for travel times based on consistency with neighboring arrival time picks.

Two Ways to View the Data set

Ray Paths

North America

Eurasia

"Hit Count"

Log_{10}(hit count)
Pn Tomographic Results: Eurasia
Pn Tomographic Results: North America

Starting Model

Tomography Model

Mantle Velocity

Mantle Gradient

Legend:
Gradient (1/s)
Non-Circular Validation Tests

Starting model
Pn velocity

Model randomization and random selection of 90% of data set

Randomized Pn velocity

Pn velocity randomized 0.1km/s RMS
3 realizations

Tomographic realizations

Tomographic realization

Pn velocity (km/s)

7.65  7.85  8.05  8.25
Tomography Dramatically Improves Travel Time Prediction for Regional Phases Across Eurasia

**Pn**

- ak135
- Starting model
- RSTT tomographic model

**Sn**

- ak135
- Starting
- Tomography

**Pg**

**Lg**

Distance (degrees)

Distance Degrees

Median Error (s)

Traveltime Error (s)
Improved Regional Location Accuracy (Eurasia)

- Epicenter error is reduced by approximately a factor of 2.
- Largest improvement for sparse networks.

![Graph showing median epicenter error vs. number of Pn phases for different models: ak135, Starting, RSTT. The graph indicates a decrease in error as the number of Pn phases increases.]

![Map of Eurasia with validation events marked. The map indicates that these events were not used in tomography.]
Location Improvement Varies By Region

- RSTT epicenter accuracy in Eurasia and North American are similar.
- Dramatic reduction in epicenter error in Eurasia due to poor performance of \textit{ak135}.
- \textit{ak135} epicenter errors much smaller in North America than Eurasia.
Validated Uncertainty

- RSTT ellipse area is smaller than ak135, regardless of the number of data used.
- RSTT significantly increases the number of ellipses with area less than 1000 km². CTBT limits on-site inspections to 1000 km².

Example Ellipse

Lop Nor Event, June 8, 1986
Regional Phases Only

![Map and diagrams showing RSTT ellipse area comparison with ak135 model, showing increased number of ellipses with area less than 1000 km².](image-url)
• Pn, Pg, Sn, Lg tomography completed in Eurasia
• Pn tomography completed in North America
• Data sets from additional regions would enable extension of RSTT tomography
Conclusions

- RSTT accounts for crust and upper mantle heterogeneity.
  - Improves regional travel time prediction and location accuracy.
  - Provides confidence that using regional data will improve location accuracy.

- Travel time uncertainty is well characterized.
  - Epicenter ellipses are representative of observed error.

- Computational speed of ~1 msec is sufficient for operational use.