SnT 2025 8 SEPTEMBER ONLINE DAY 9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE
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Variable Global Grid Refinement and Travel-Time Prediction using the RSTT Model

Ranasinghe, N. R[1], Begnaud, M. L.[1], Rowe, C. A.[1], Myers. S. C.[2], Young, B.[3]

[1] Los Alamos National Laboratory [2] Lawrence Livermore National Laboratory [3] Sandia National Laboratories

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This research is supported by Ground-based Nuclear Detonation Detection (GNDD) and Office of Nuclear Verification research programs that are funded by the National Nuclear Security Administration (NNSA), Defense Nuclear Nonproliferation (NNSA DNN).

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RSTT Model

- The Regional Seismic Travel Time (RSTT) is a global model (Myers et al. 2010, Begnaud et al. 2021, 2021a) that rapidly predicts travel times of regional seismic phases (Pn, Sn, Pg and Lg)
- RSTT accounts for Moho, crystalline crust layers, sedimentary layers and surface water/Ice layers of the 3-D crustal and upper mantle structures.
- RSTT models utilize a model grid of constant ~1º cells.
- Pn/Sn travel time (TT) in the RSTT model is given as:

$$TT = \sum_{i=1}^{N} d_i s_i + \alpha + \beta + \gamma$$

RSTT Global Tessellation at ~1º

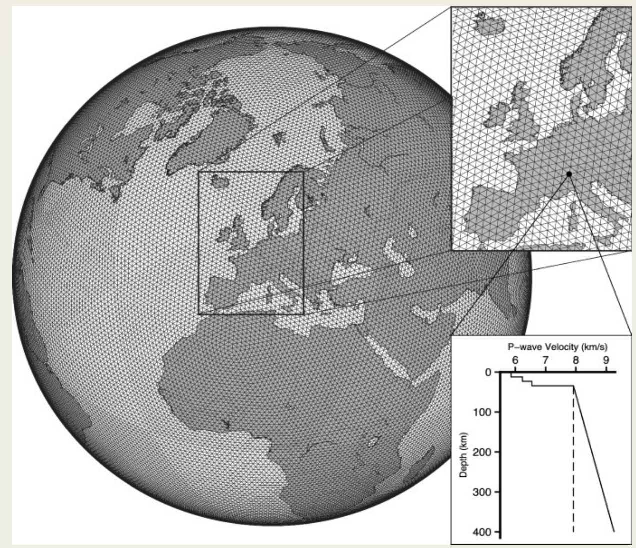
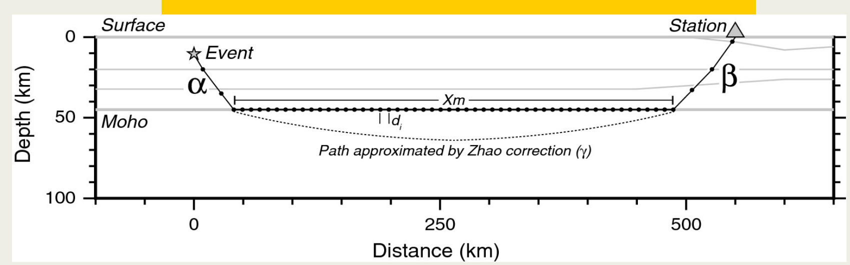


Illustration of a Pn/Sn wave in RSTT



Begnaud et al. 2021, "Updates to the Regional Seismic Travel Time (RSTT) Model: 1. Tomography"

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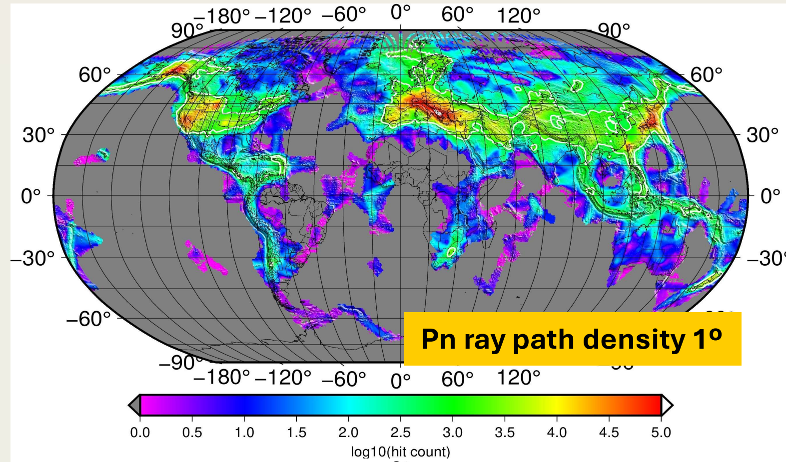
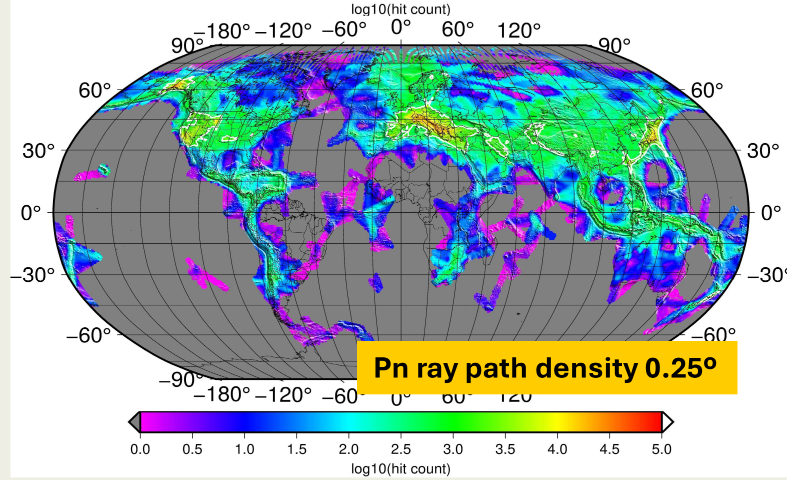
Grid Refinement in RSTT

- Babikoff et al. (2022) implemented data driven grid refinement of upper mantle Pn velocity and upper mantle velocity gradient in Israel and the Middle East using Pn and Pg waves for *1° → 0.5° → 0.25° → 0.125°*.
- They successfully image smaller velocity features and improved travel time prediction in the region.
- A data driven global grid refinement of RSTT is warranted in regions (western U.S., Europe and the Middle East and East Asia) with high density ray path coverage to improve travel time prediction.





Ranasinghe et al. 2025, "Data-informed Grid Refinement to Improve Travel Time Accuracy in the Regional Seismic Travel Time (RSTT) Model

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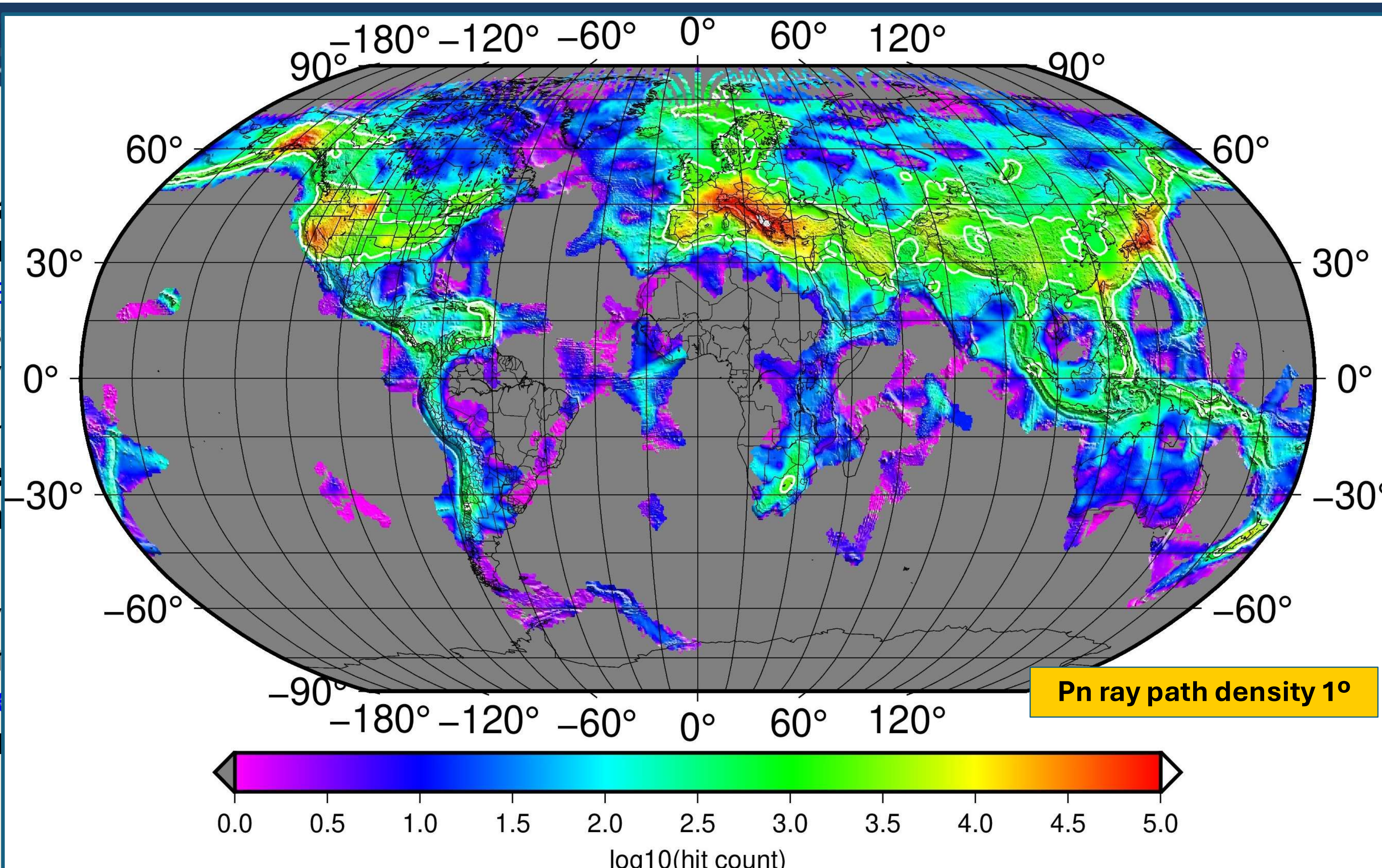

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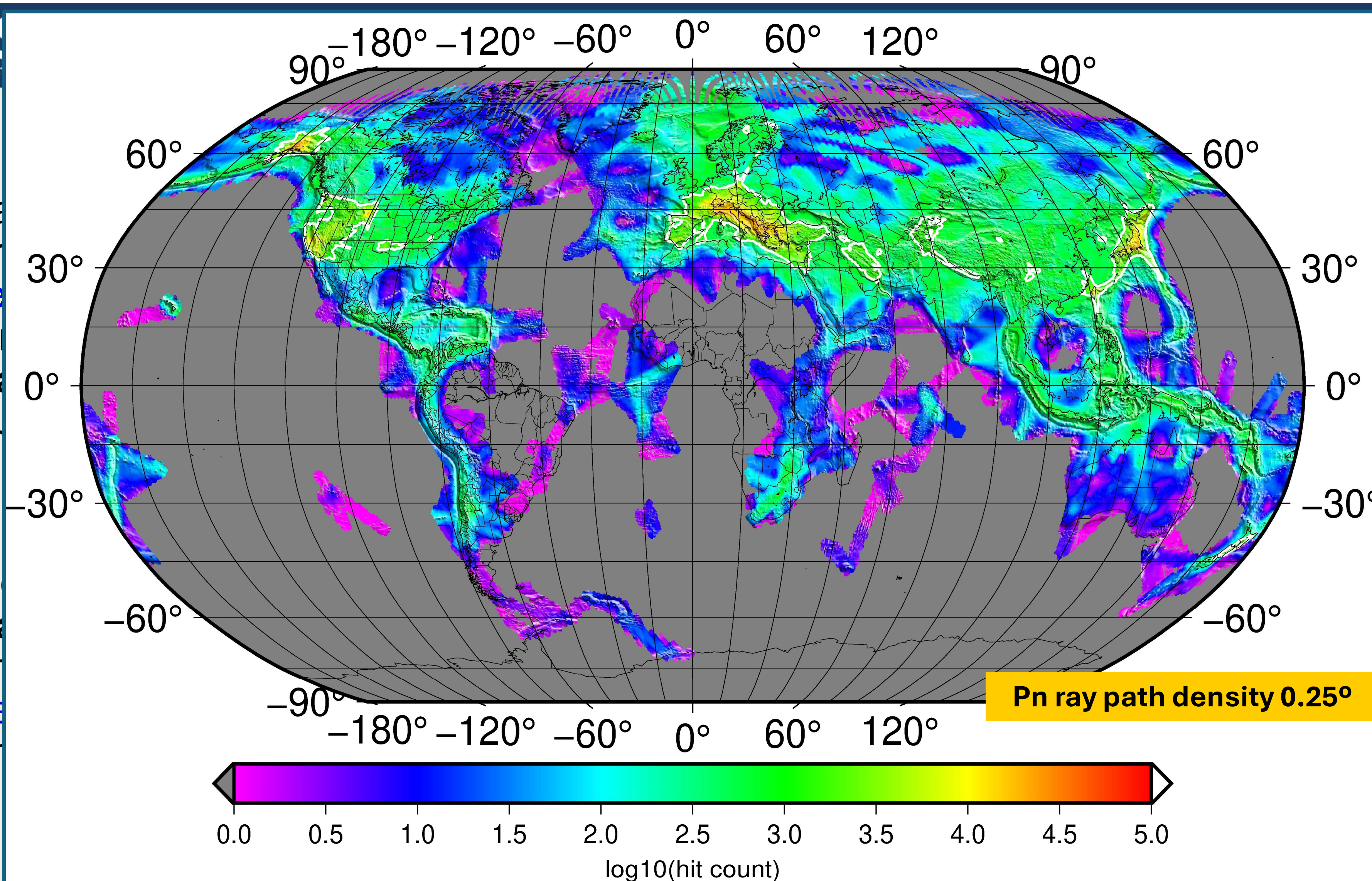

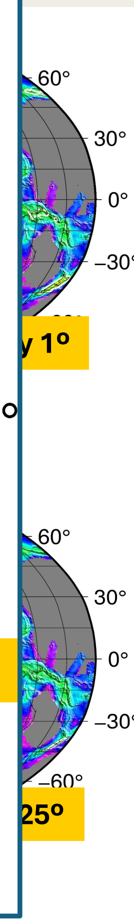

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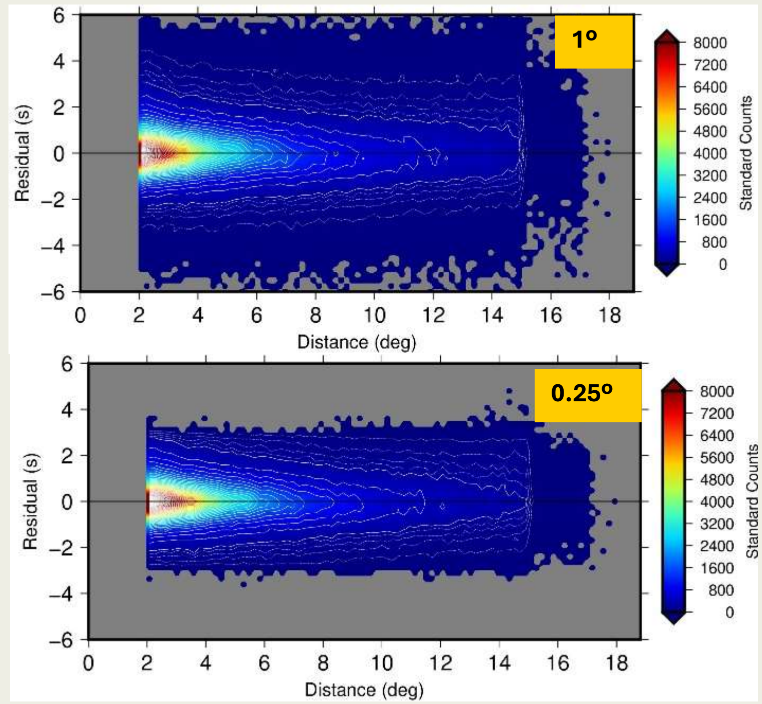
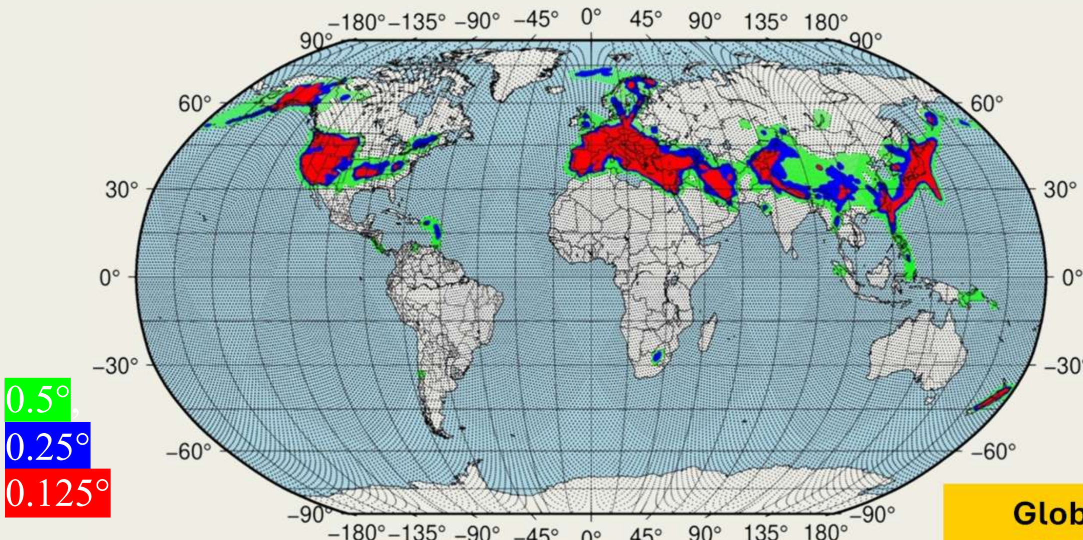
Data

- Pn travel time data for the current study is taken from a global compilation of seismic data (Begnaud et al., 2021)
  - GT≤25 or better events.
    - Relocated with Bayesloc relative relocation algorithm (Myers et al., 2007)
  - Events with focal depths above the Moho
  - Epicentral distances between 2° to 18°
- Removed phase arrivals whose TT residuals exceeded 3 STD from the mean

2D histograms of travel time residuals versus distance





Global map of tessellation points at different grid levels

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Grid Refinement Method

- Grid sizes were refined from 1° to 0.125° while adjusting smoothing and damping values using L-curve tests for upper mantle velocity and gradient
- A high damping value was used for cells with < 300 crossing ray paths
- Suitable damping and smoothing values were determined at each grid level
  - Initially for upper mantle slowness
  - Then for upper mantle gradient, holding the chosen value for the slowness values steady
- For each grid level, we performed tomographic inversions, incorporating event terms which enhanced the residual reduction and inversion stability

Grid Level	Upper Mantle Slowness		Upper Mantle Gradient	
	Damping	*Smoothing*	*Damping*	*Smoothing*
1.0°	0.5	0.2	0.3	0.5
0.5°	0.3	0.2	0.2	0.75
0.25°	0.3	0.2	0.2	1.0
0.125°	0.3	0.2	0.4	1.5

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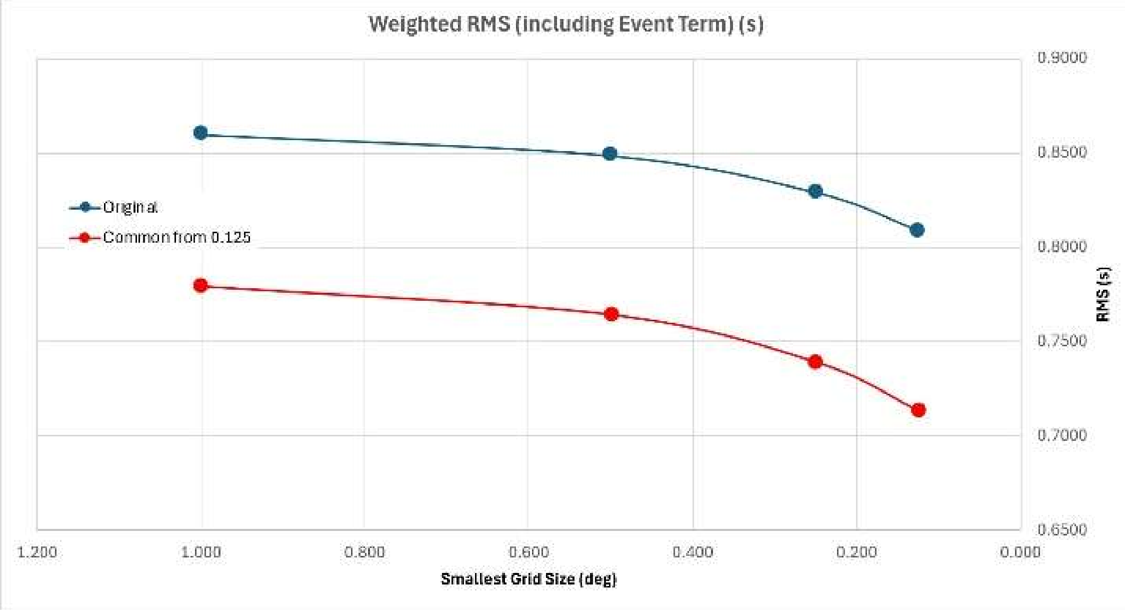
Change of Travel Time Residuals from 1° to 0.125°

- RMS Pn travel time residual changes with each grid refinement
  - Original data
  - Common to all grid refinements (due to outlier removal)
- The RMS of the Pn travel time residual reduced by 7.6% from 1º to 0.125º.
- At 0.125º grid level:
  - 8,184 stations
  - 61,797 events
  - 1,142,792 ray paths

RMS residual changes with each grid refinement



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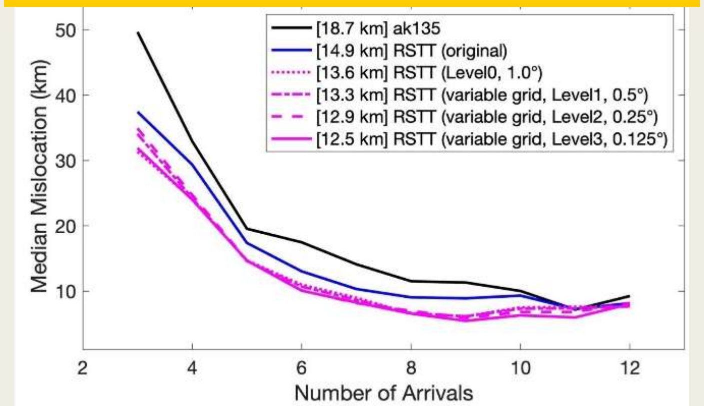
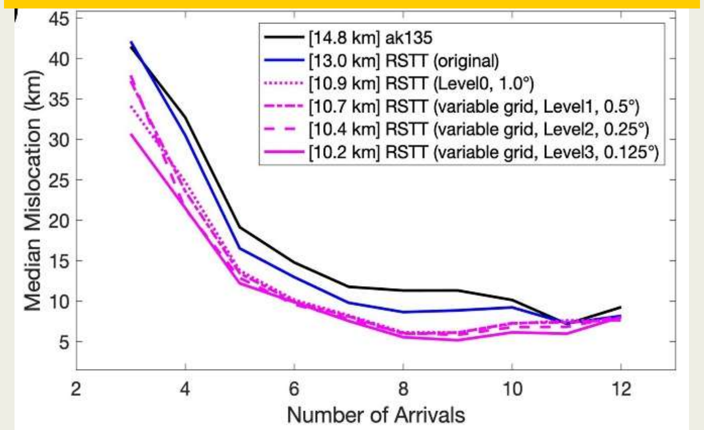
Mislocation of Validation Events

- 1395 validation events used from Begnaud et al. (2021) (not included in tomography)
- Median mislocation reduction for Global arrivals and the 0.125° grid:
  - **ak135**: 33.5%
  - **Original RSTT model**: 16.1%
- Median mislocation reduction for Europe and the Middle East arrivals and the 0.125° grid:
  - **ak135**: 32.4%
  - **Original RSTT model**: 21.6%
- Globally most validation events were recorded by < 6 stations

Global mislocation relative to number of Arrivals



Mislocation relative to number of Arrivals: Europe and the Middle East



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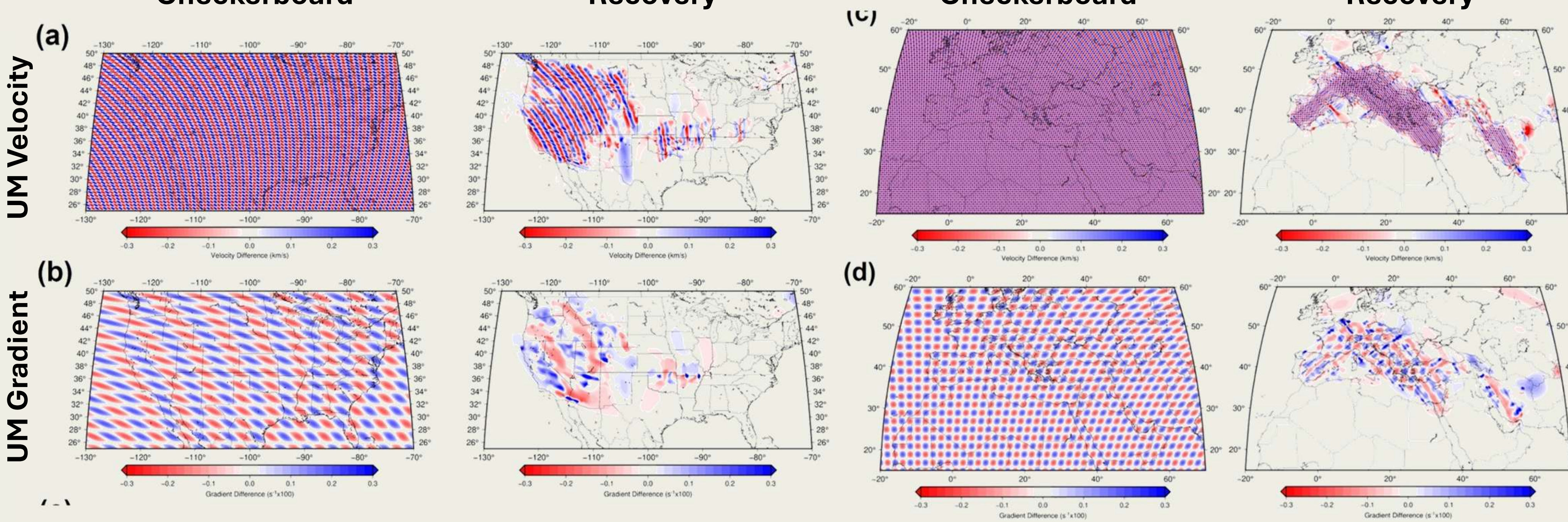
Checkerboard Tests



Contiguous U.S. *Europe/Middle East*

Rays are calculated through these checkerboard models to create synthetic "observed" travel times for tomography tests, mimicking the main tomography runs.

Upper mantle (UM) velocity: 0.5° size with ±0.5 km/s amplitudes
UM Gradient: 2° size with ±0.002 s^{-1} amplitudes

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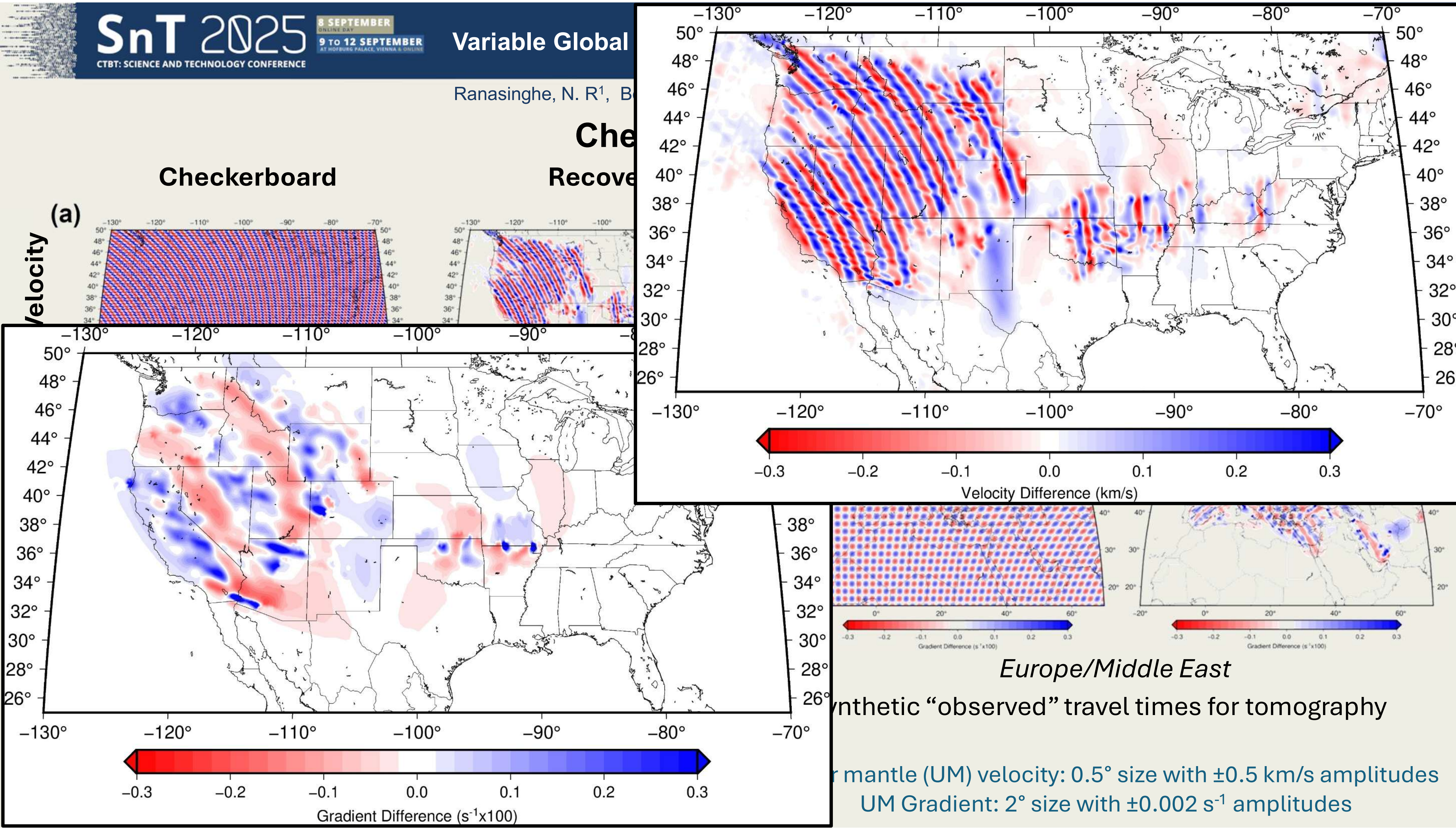

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Velocity Difference (km/s)
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Gradient Difference (s-1x100)
Europe/Middle East
ynthetic “observed” travel times for tomography
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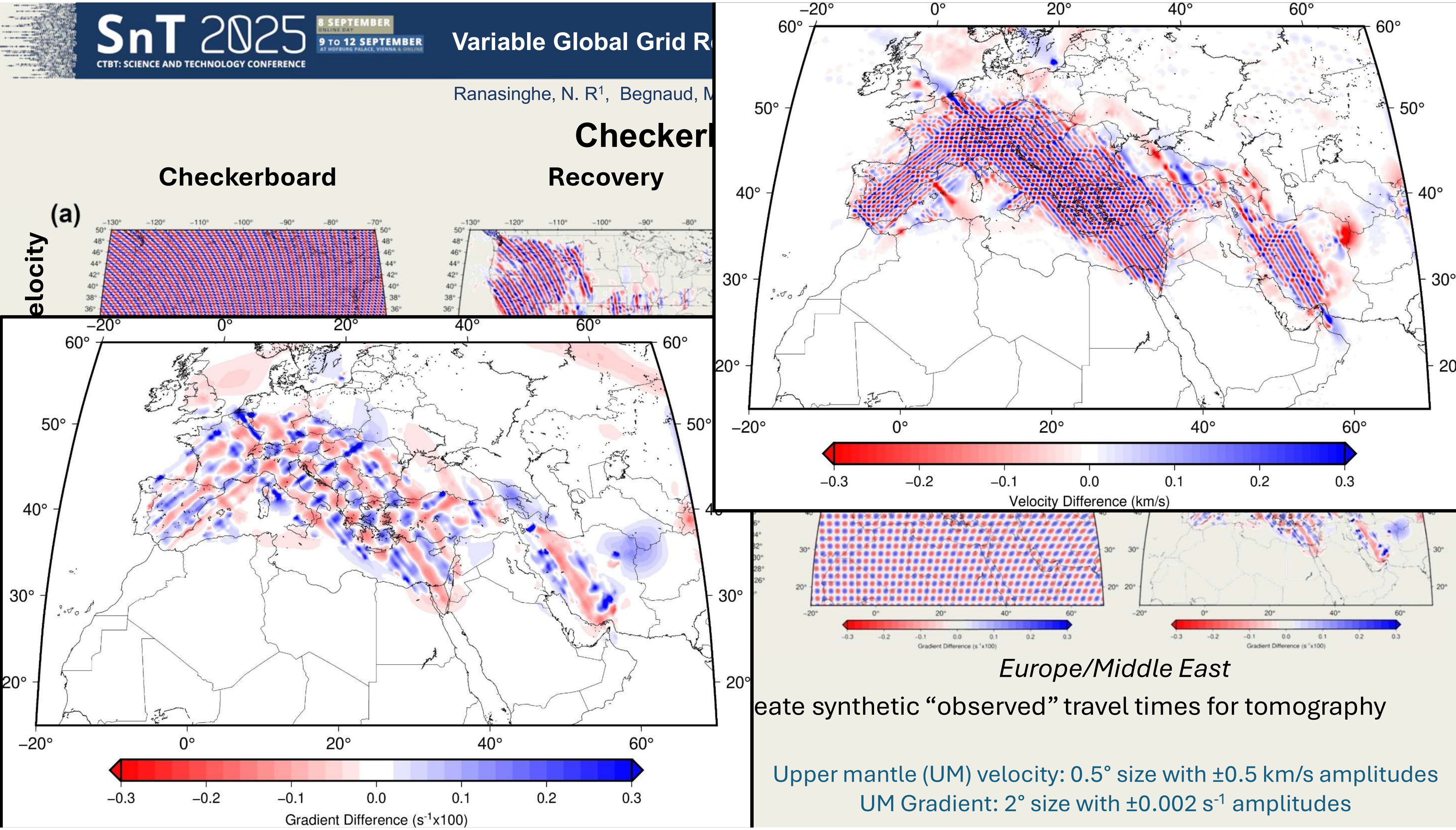

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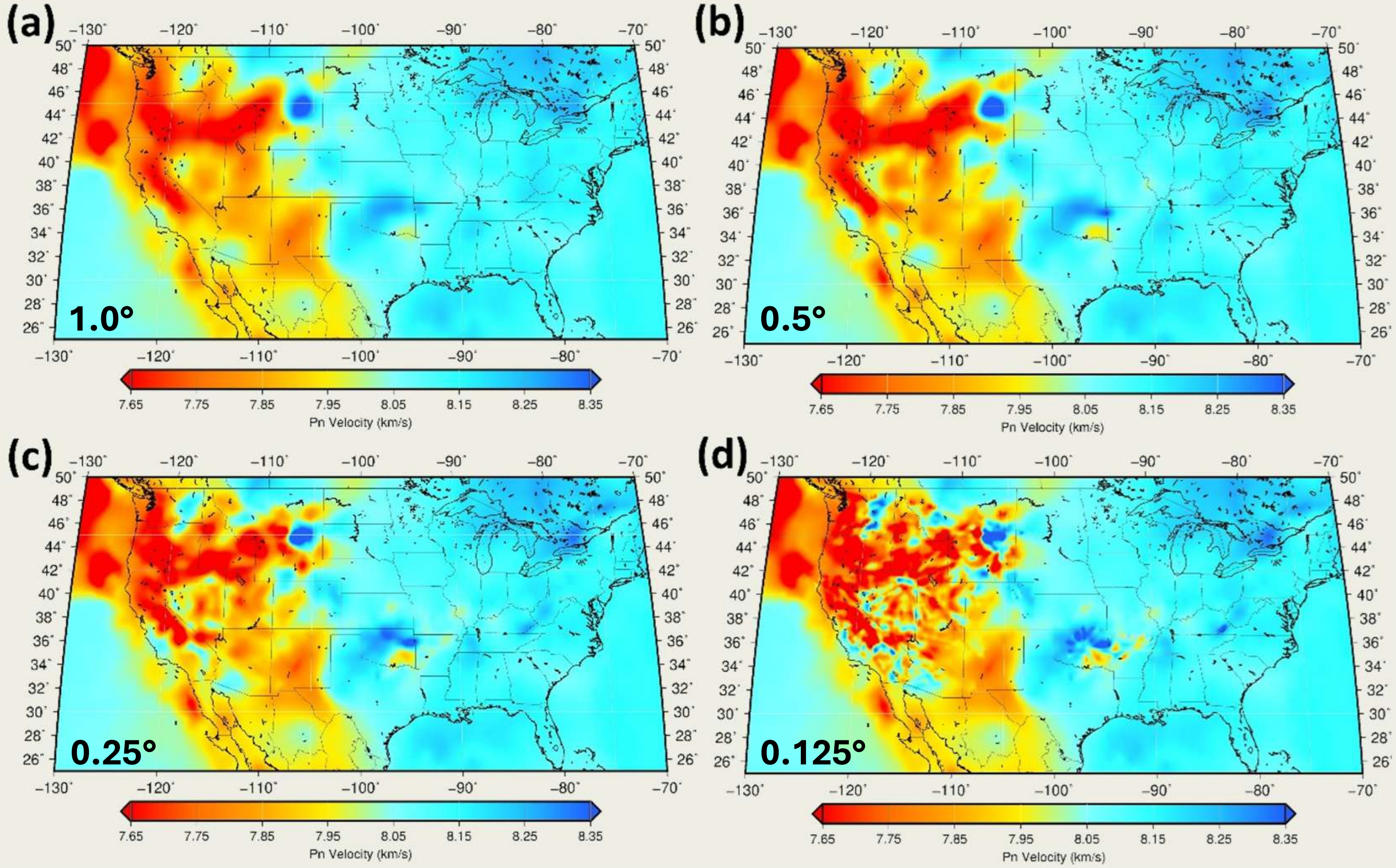
Grid Refinement in the Contiguous U.S.: Upper Mantle Pn Velocity



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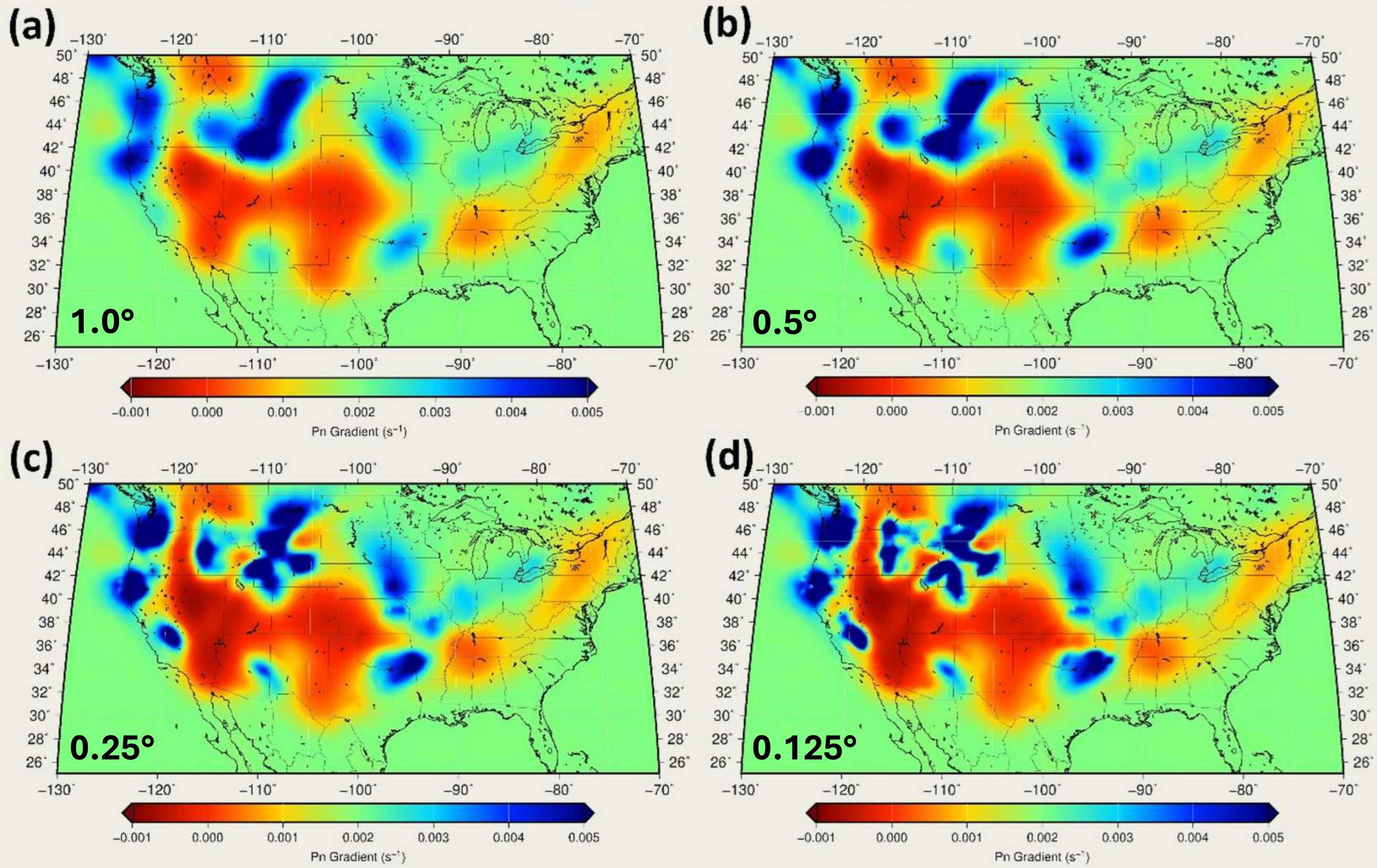
Grid Refinement in the Contiguous U.S.: Upper Mantle Pn Gradient



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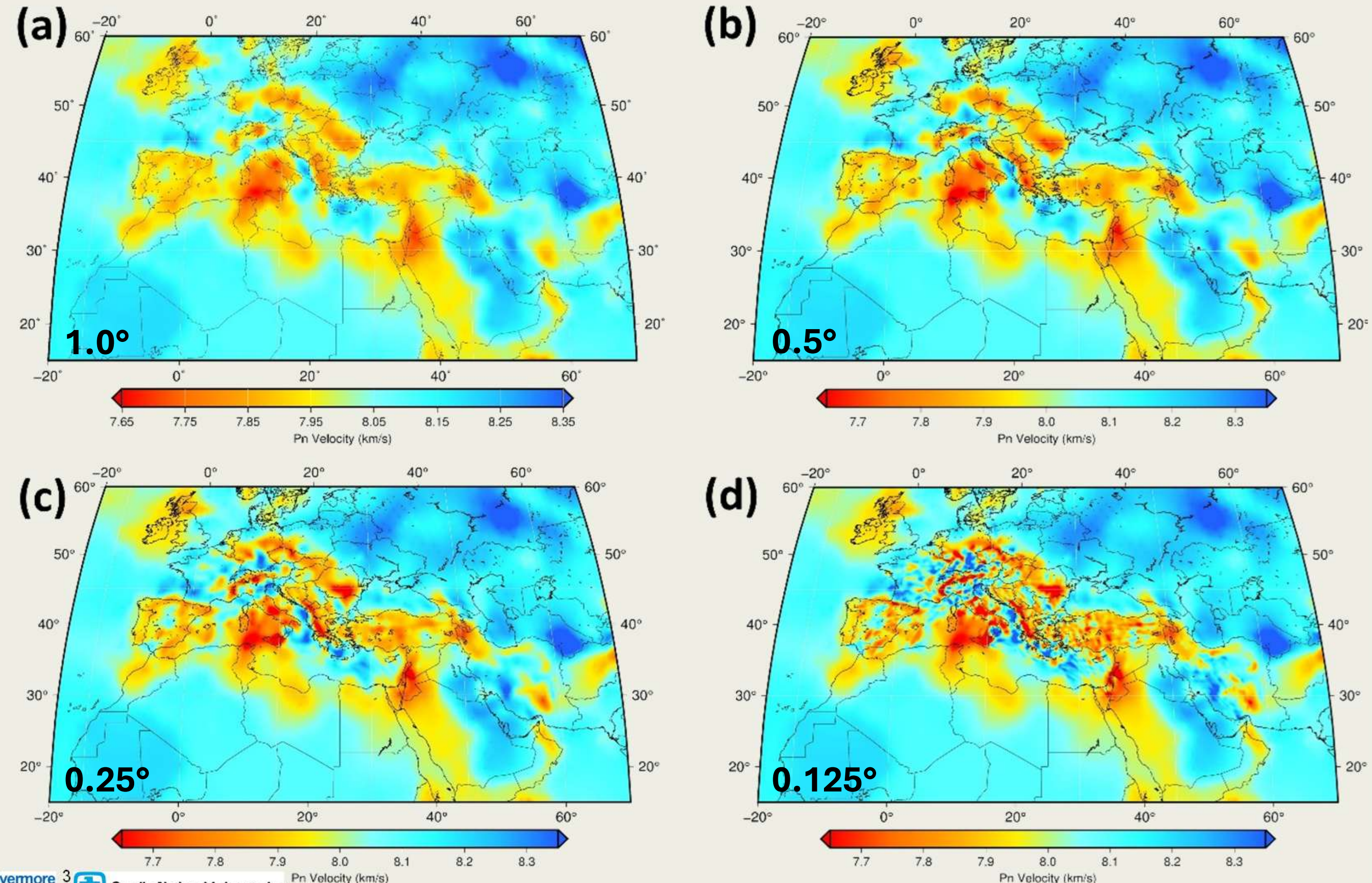
Grid Refinement in Europe/Middle East: Upper Mantle Pn Velocity



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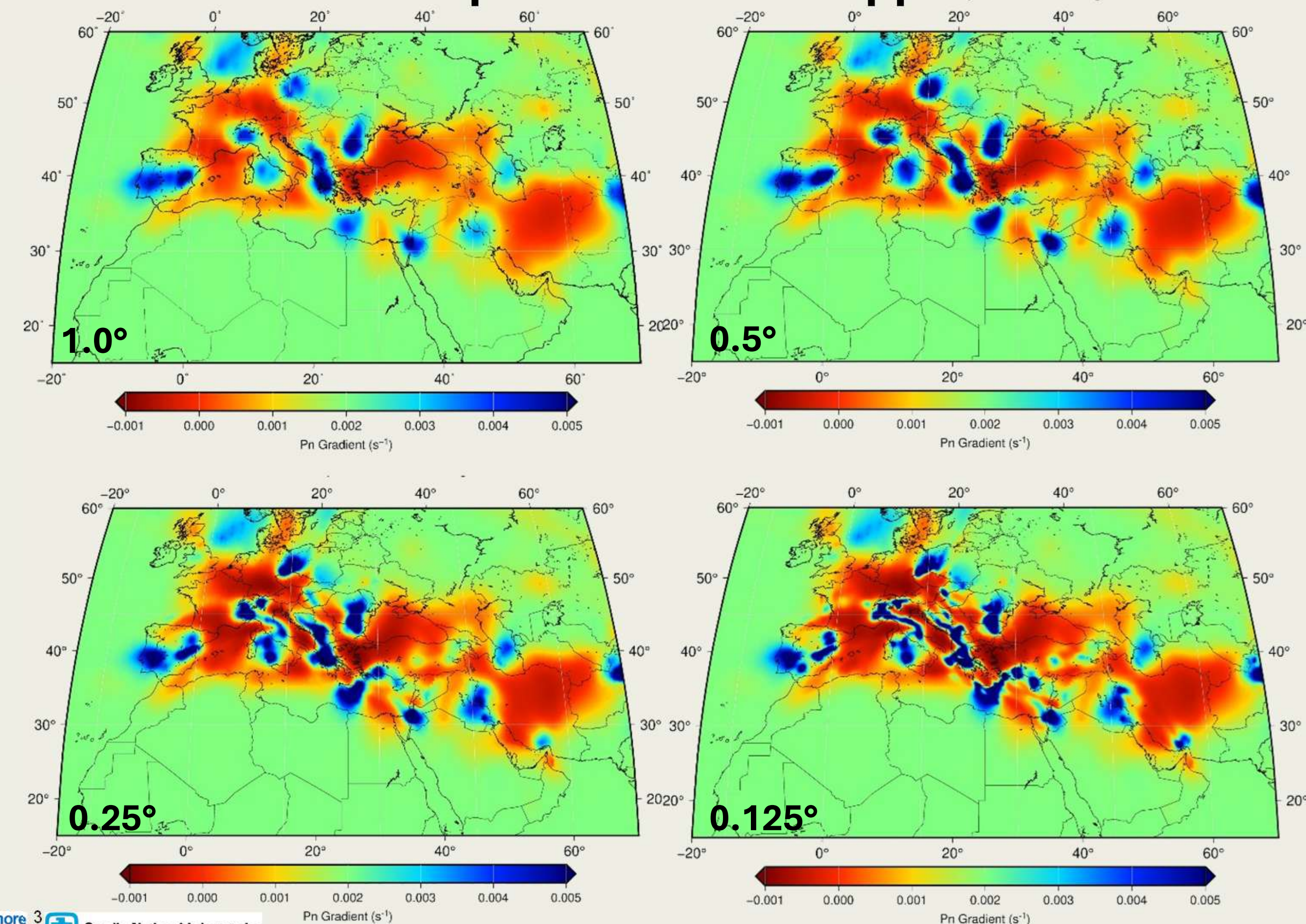

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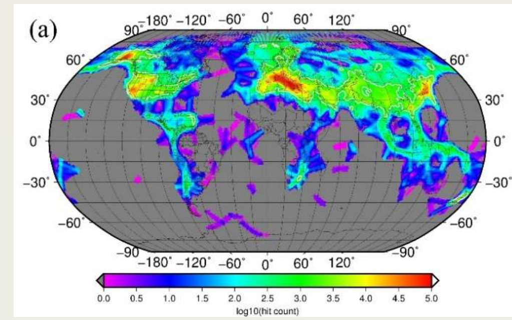
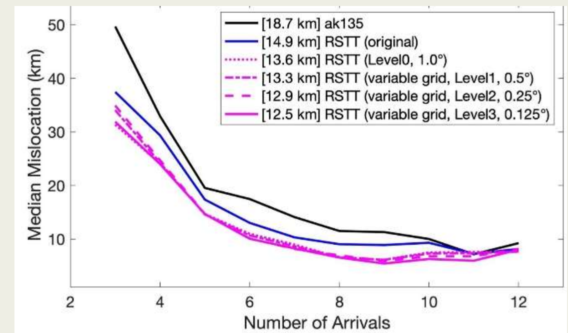
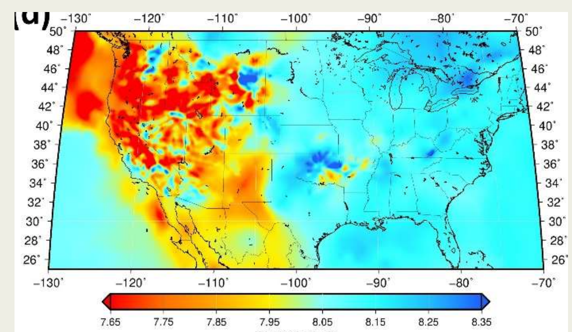
Conclusions

- High Pn ray density in the Western U.S., Europe and the Middle East, and East Asia enable systematic global grid refinement up to 0.125° (~14 km) using RSTT model.
- L-curve method was utilized to identify appropriate damping and smoothing values at each grid level.
- RSTT grid refinement improved the Pn travel time prediction by 33.5% and 32.4% globally and Europe and the Middle East, respectively, compared to *ak135 model*.
- Smaller features are better delineated in the upper mantle velocity and gradient.
- Future work includes modeling Sn, Pg, and Lg using grid refinement.







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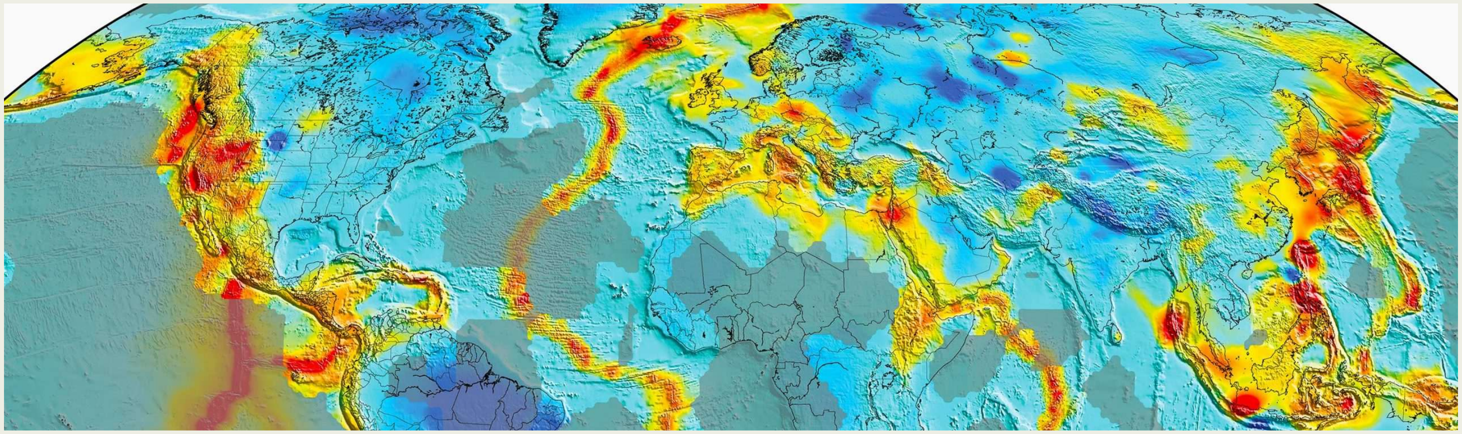
- This research is supported by Ground-based Nuclear Detonation Detection (GNDD) and Office of Nuclear Verification research programs that are funded by the National Nuclear Security Administration (NNSA), Defense Nuclear Nonproliferation (NNSA DNN).
- The current RSTT model (pdu202009Du) used as the starting model for this study can be found and downloaded from https://www.sandia.gov/rstt.
- Seismic bulletin data were obtained from public sites (e.g., IDC Reviewed Event Bulletin, United States Geological Survey, International Seismological Centre).



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