SEISMIC IMAGING:
Modeling earthquakes and Earth's interior based on Exascale simulations of seismic wave propagation

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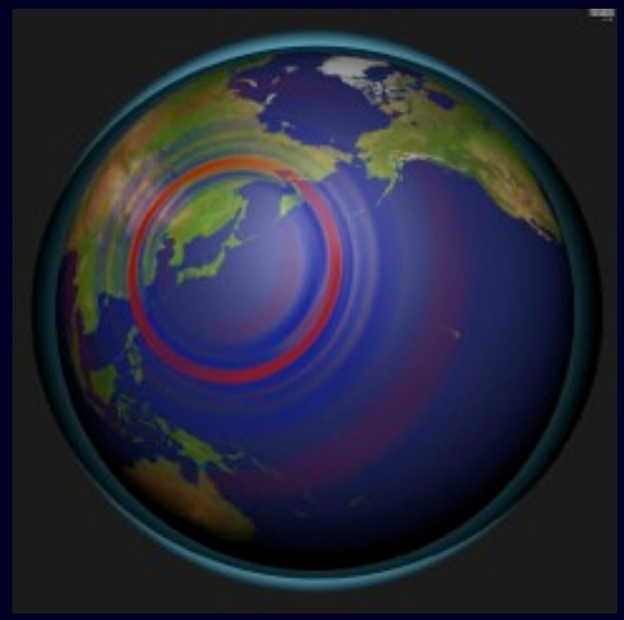
G8 Exascale Projects Workshop

Broader Impacts

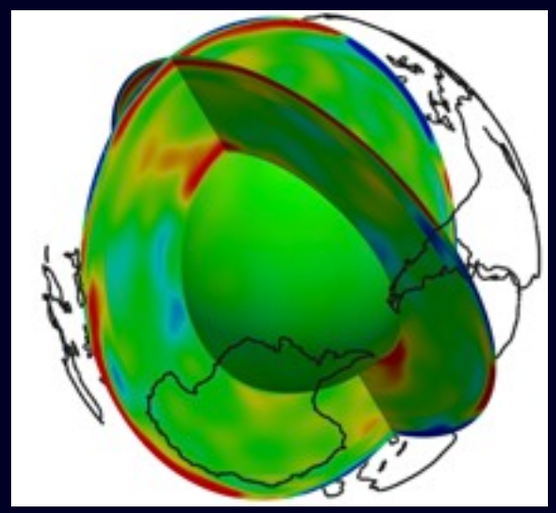
- Quantitative seismic hazard assessment
- Seismic imaging (hydrocarbon exploration)
- Seismic inversion (exploration, regional & global seismology)

Outline

Software Development



Adjoint Tomography



Outline

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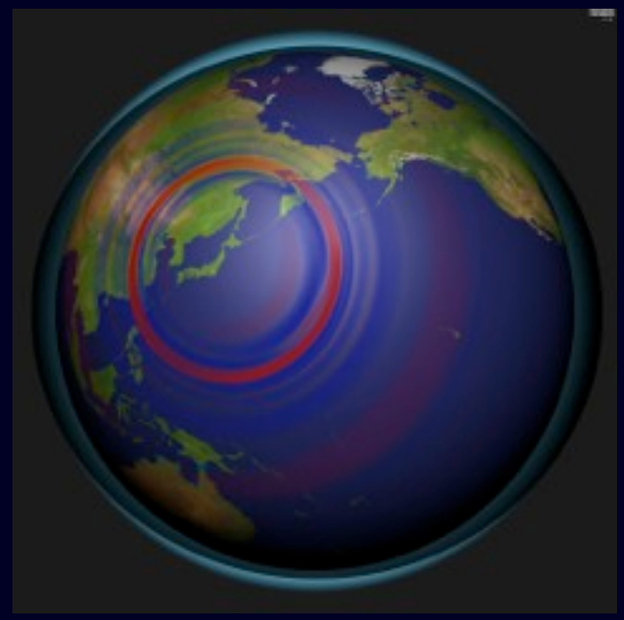
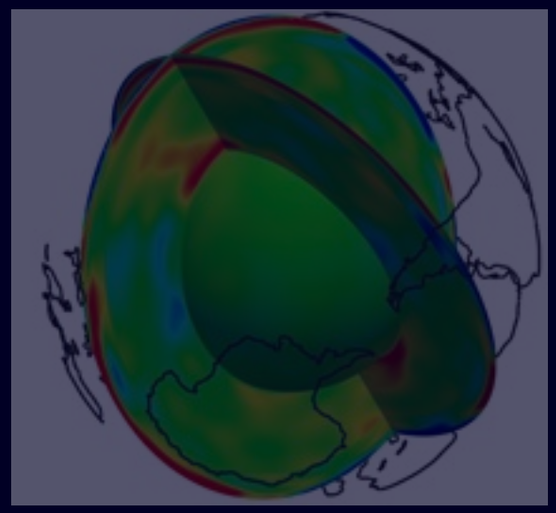


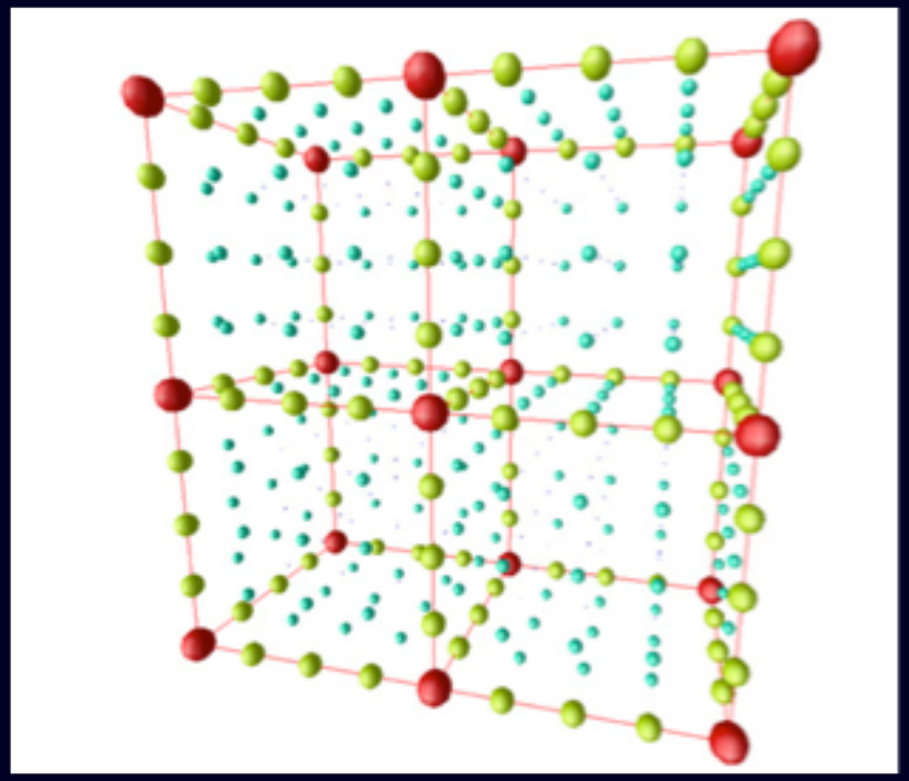
Adjoint Tomography

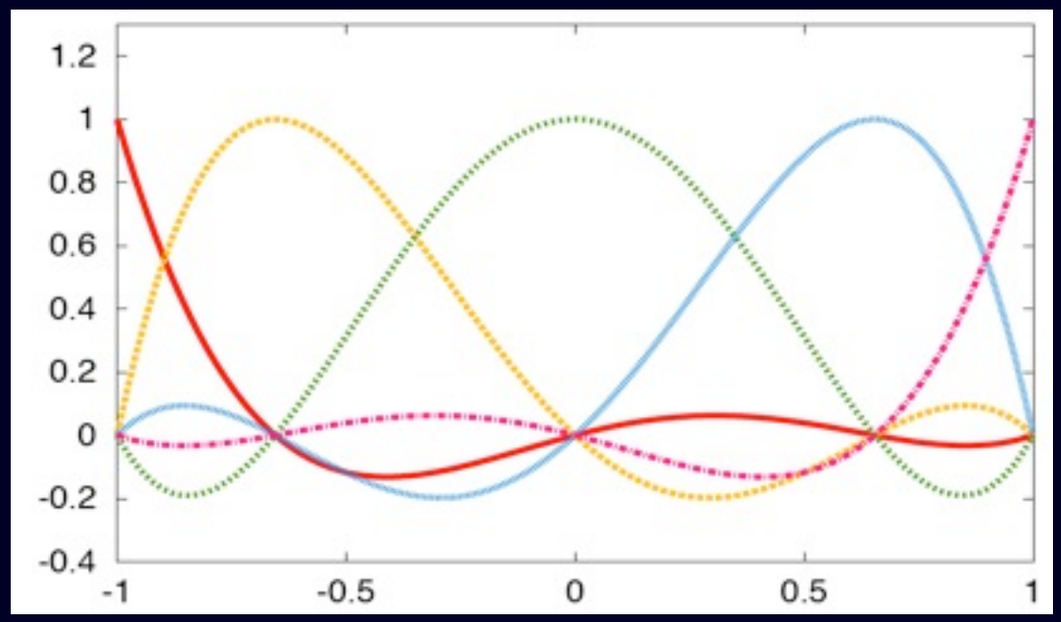


Spectral-Element Method

Spectral finite-elements:

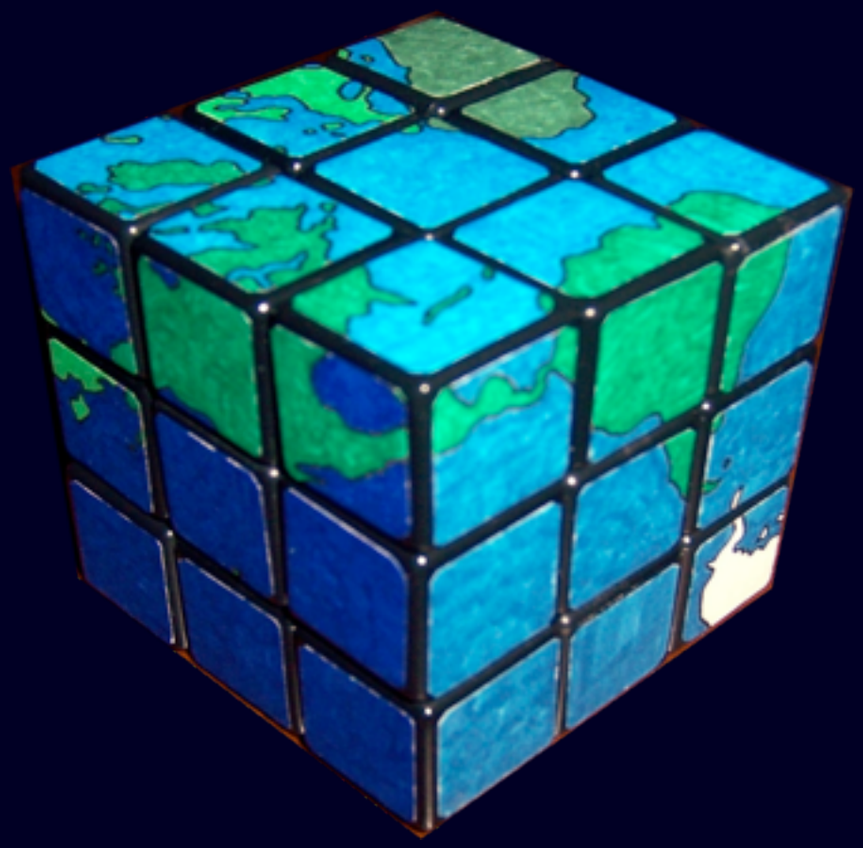
- hexahedral elements
- Lagrange interpolants
- Gauss-Lobatto-Legendre quadrature
- diagonal mass matrix
- explicit time-marching scheme

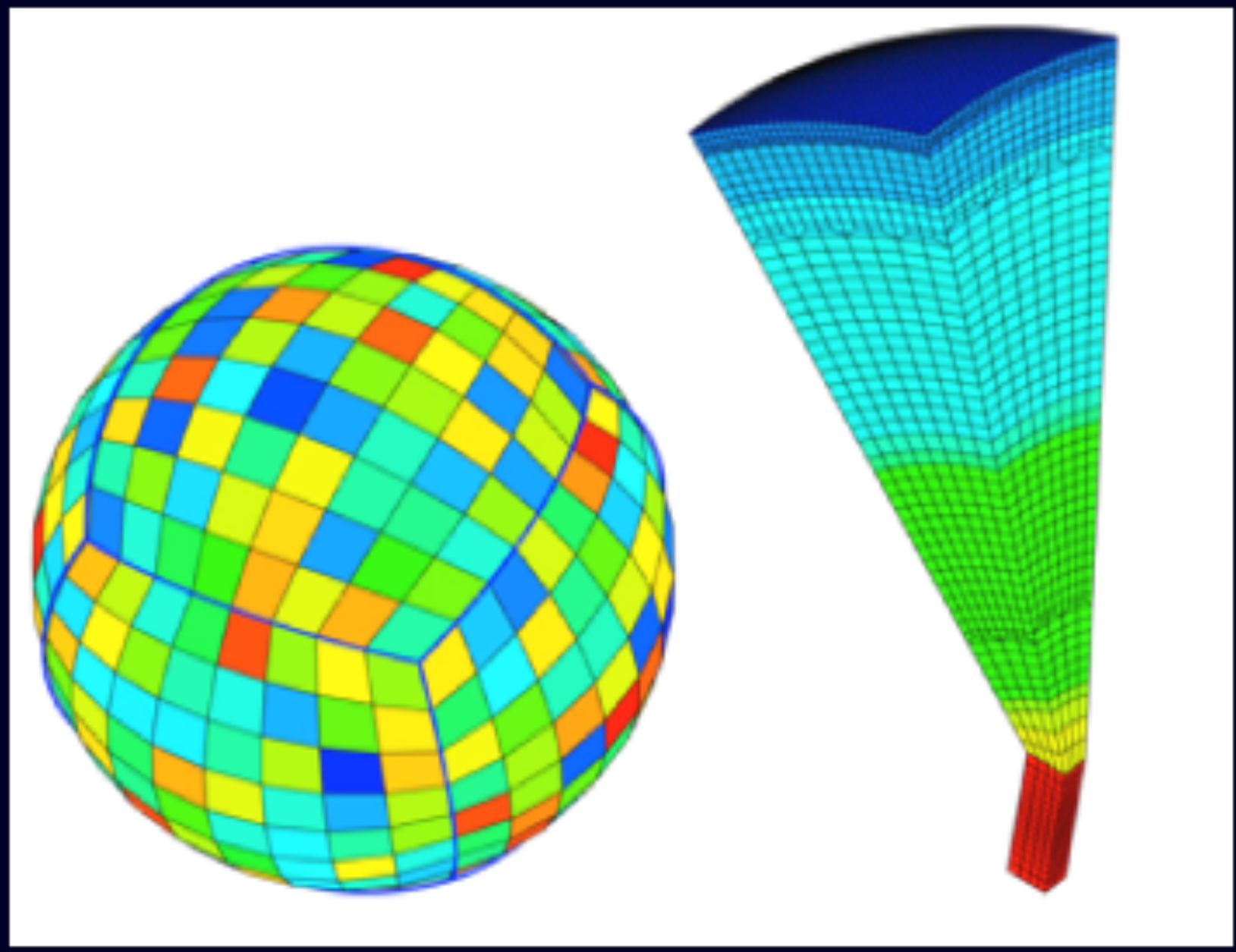




Parallel Implementation

Global mesh partitioning





SPECFEM3D_GLOBE

Cubed Sphere: 6 n^2 mesh slices

Open Source Software

SPECFEM3D & SPECFEM3D_GLOBE

- 3D crust and mantle models
- Topography & Bathymetry
- Rotation
- Ellipticity
- Gravitation
- Anisotropy
- Attenuation
- Adjoint capabilities

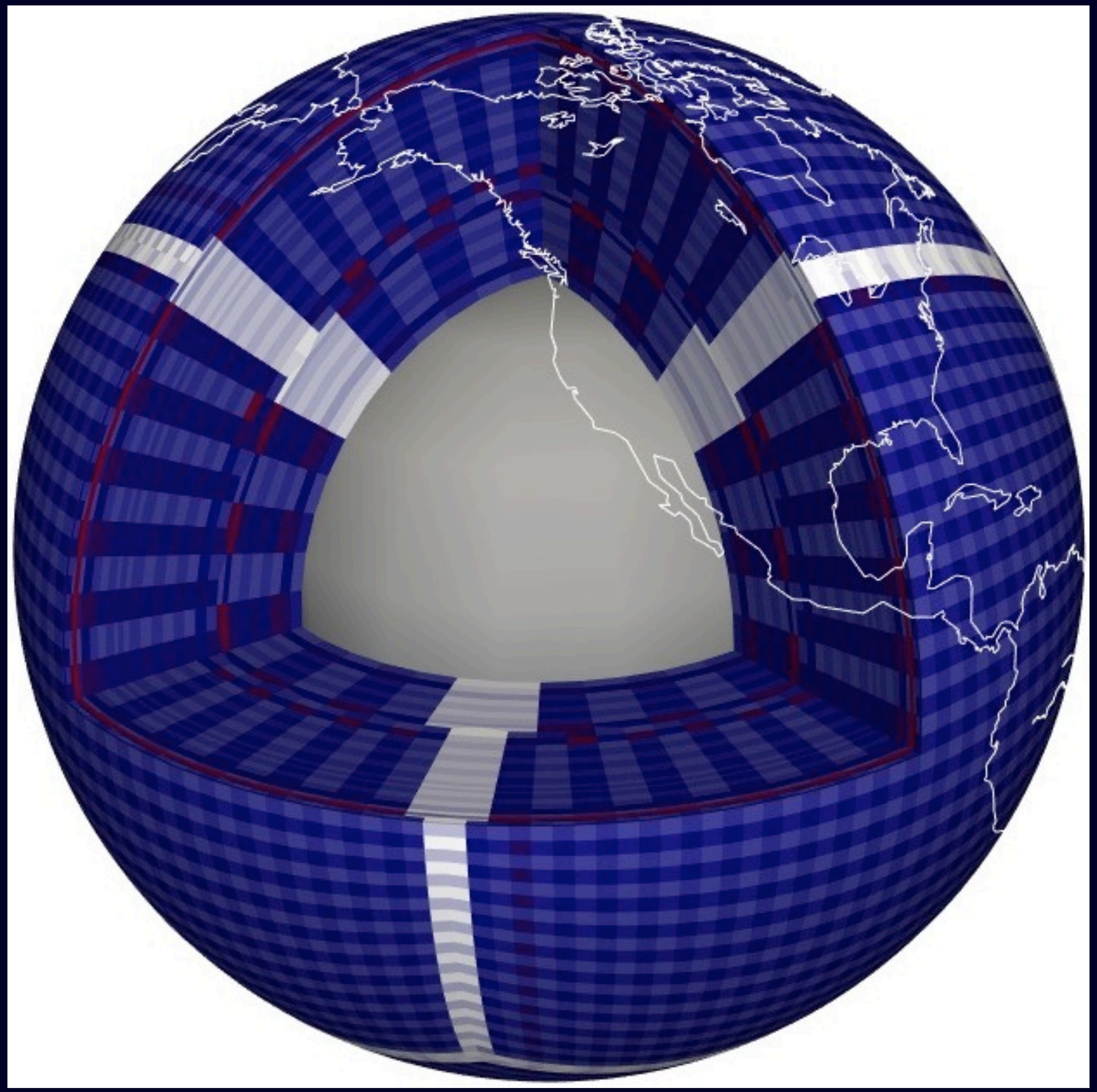
www.geodynamics.org

G8 Accomplishements & Activities

- Finished production GPU solvers
- Global *ShakeMovie* is live: near real-time, on-demand seismology global.shakemovie.princeton.edu
- Finished adjoint tomographic inversion of Europe
- Initiated adjoint tomography of Southeast Asia
- Initiated global adjoint tomography
- INCITE allocation on ORNL Titan starting January 2013
  (with Olaf Schenk, Lugano)
- Initiating collaborations with Intel (MIC) and IBM (workflows & “big data”)

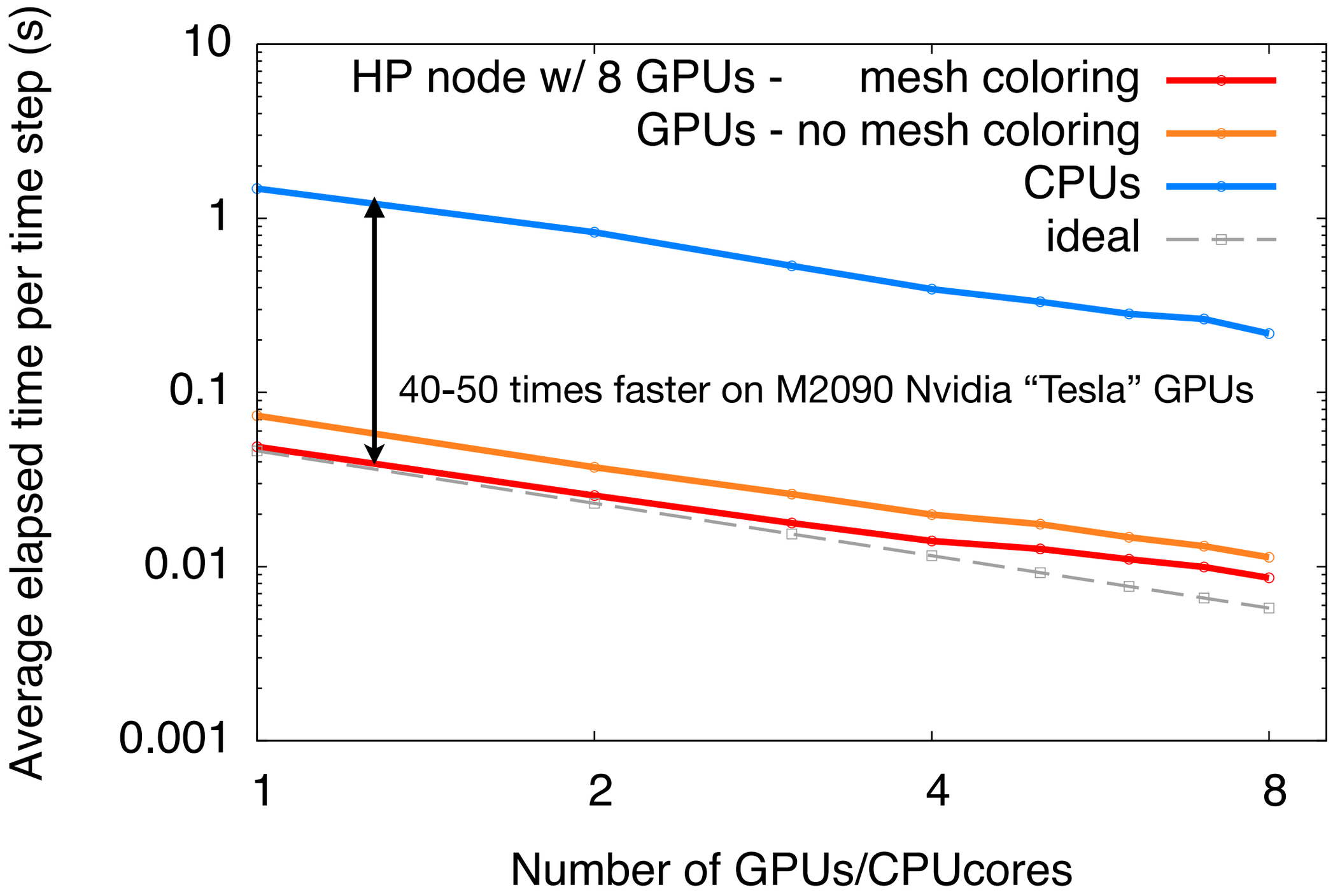
GPU Computing

SPECFEM3D_GLOBE: Mesh Coloring

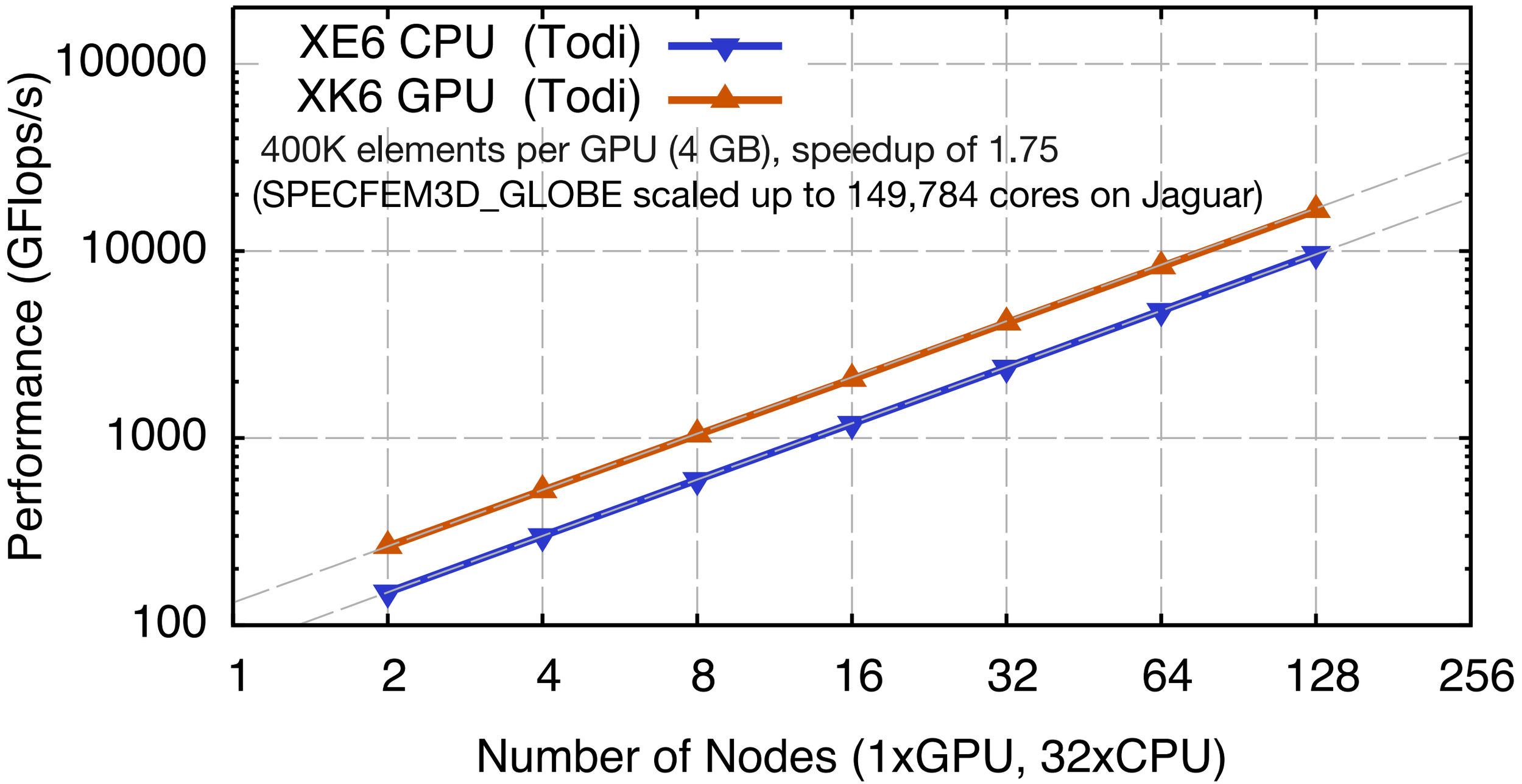


Max Rietmann, Daniel Peter & Joseph Charles

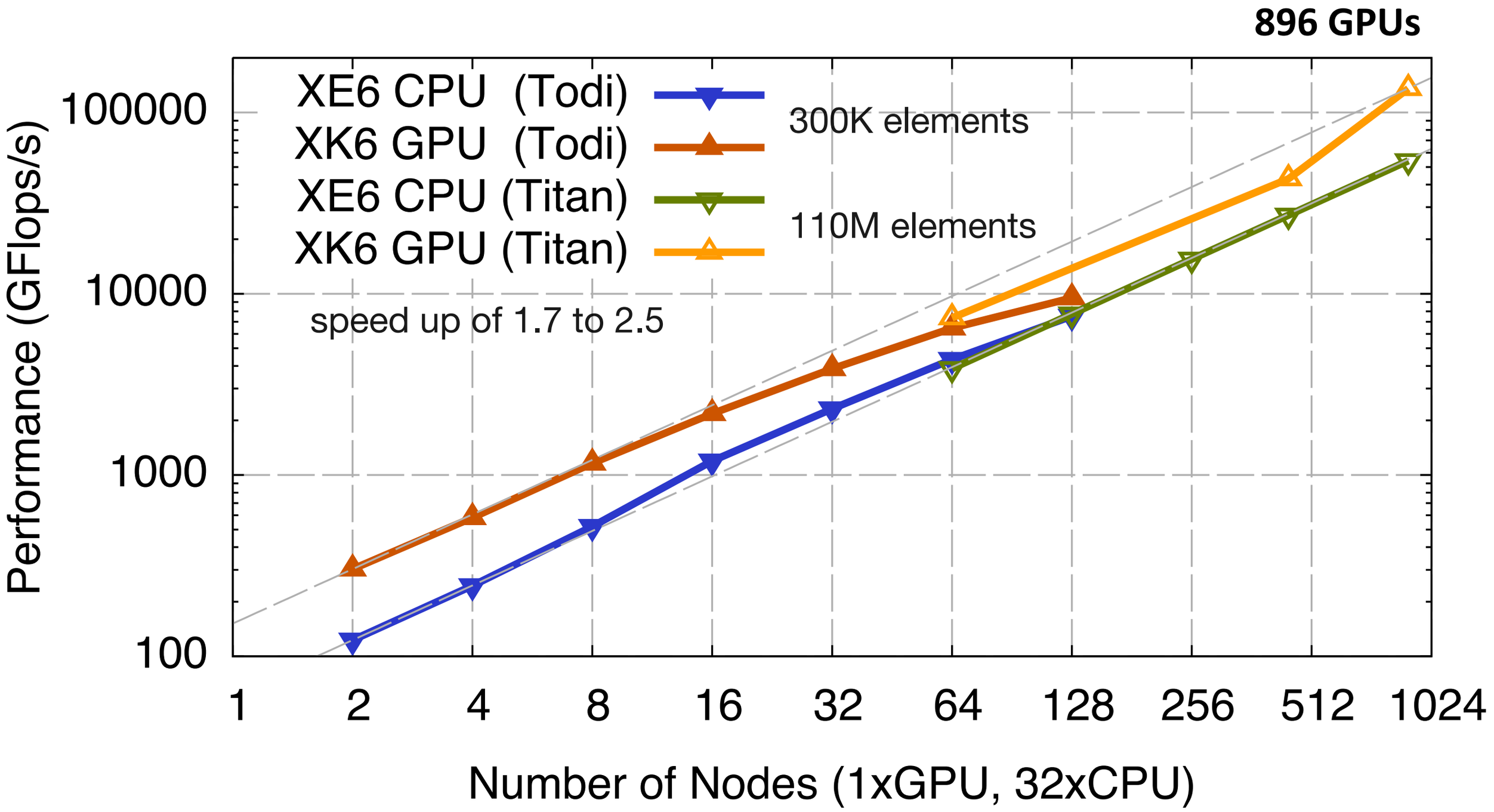
single node strong scaling GPU



weak scaling GPU

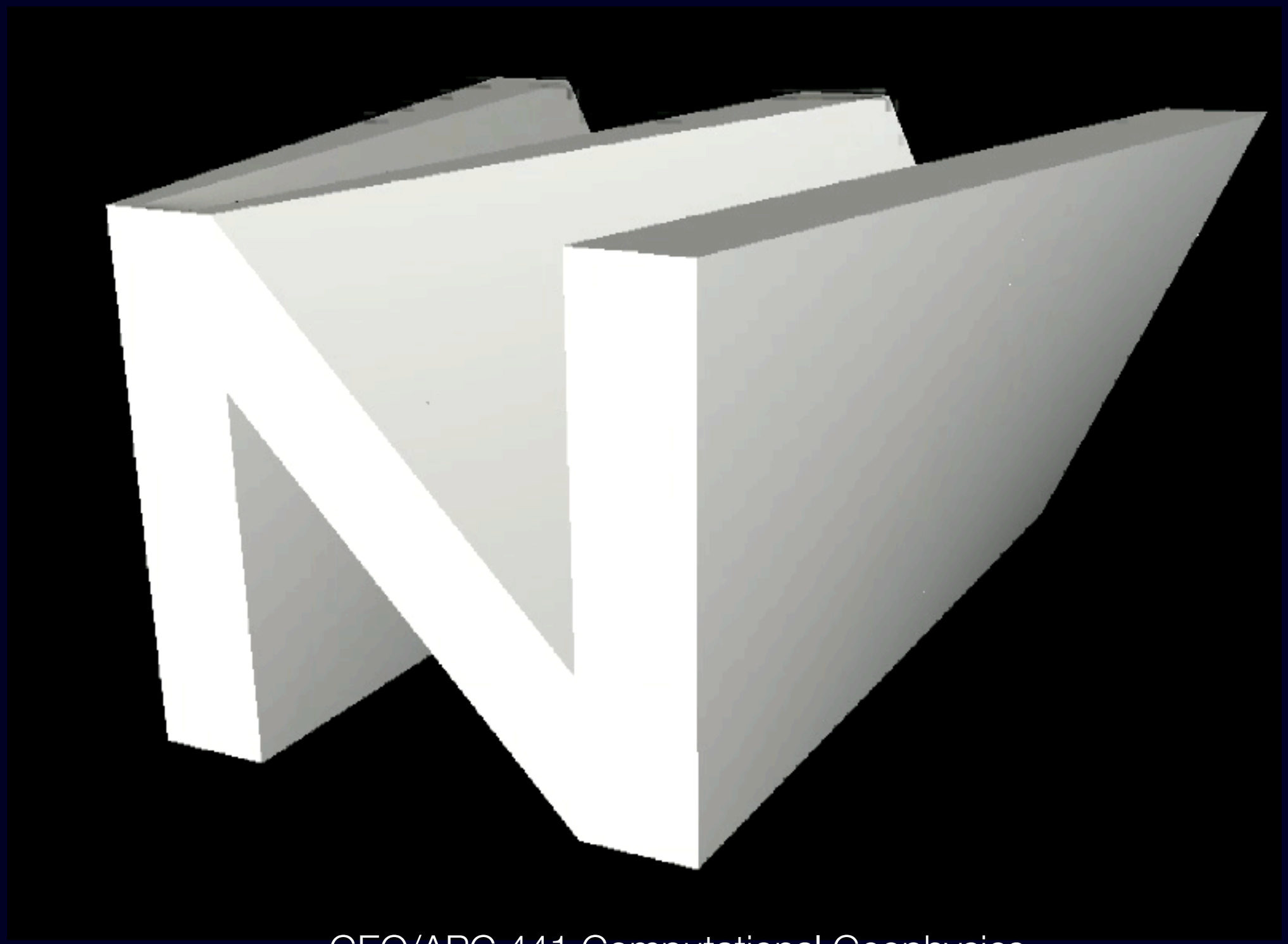


strong scaling GPU



With Peter Messmer, NVIDIA

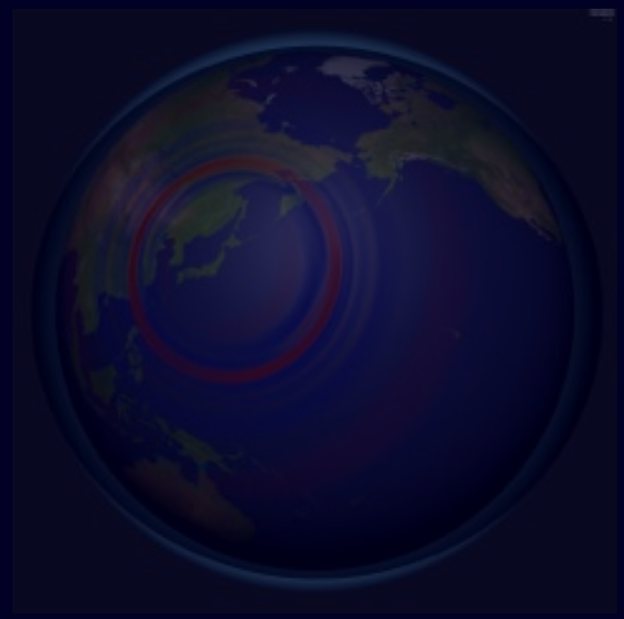
SPECFEM in Education & Training



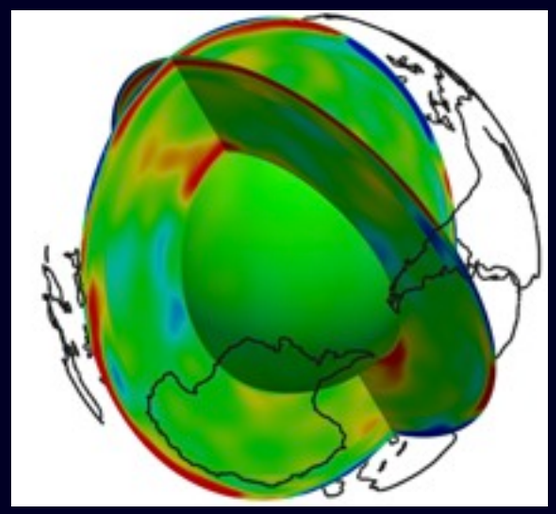
GEO/APC 441 Computational Geophysics

Outline

Software Development

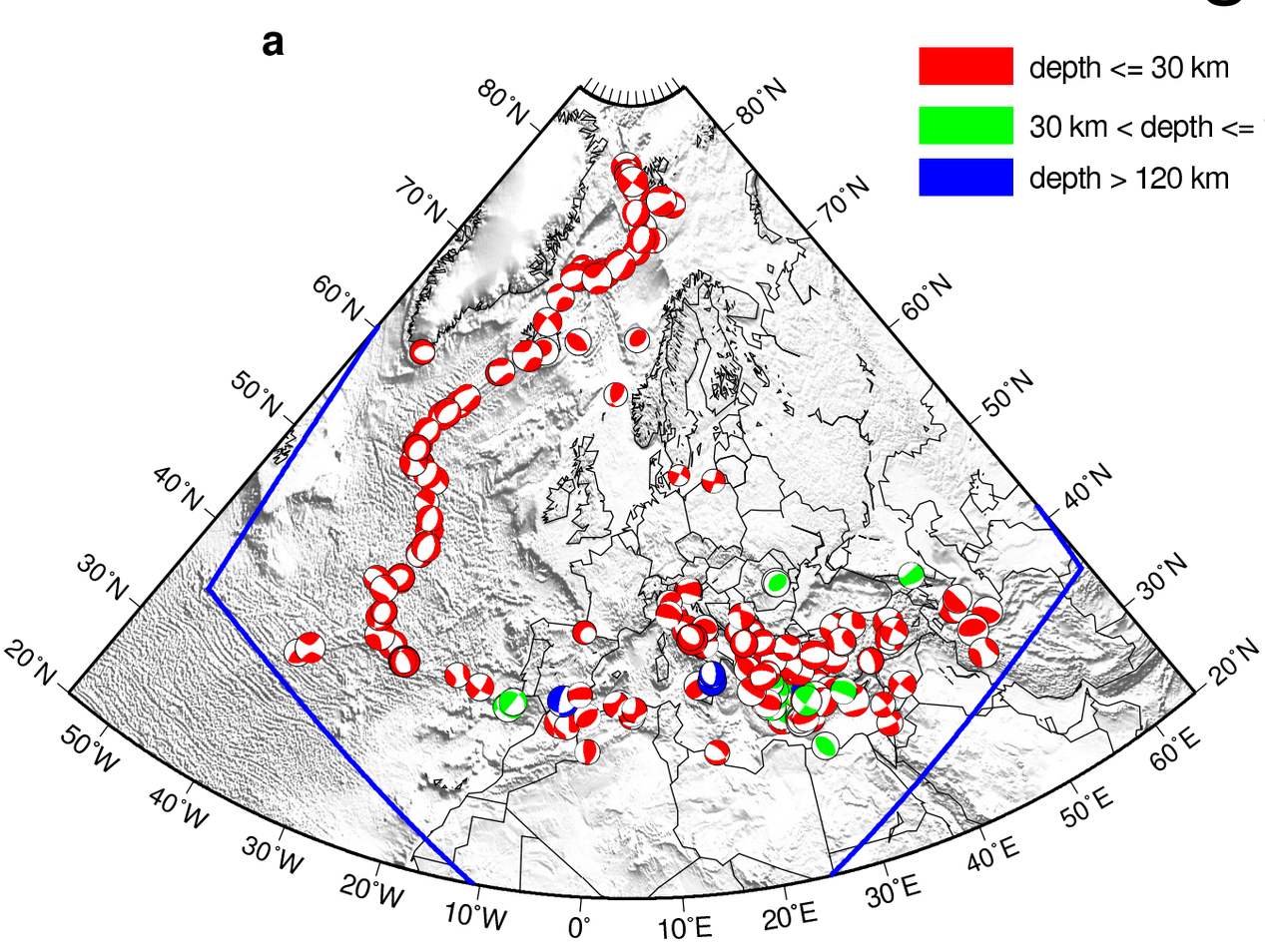


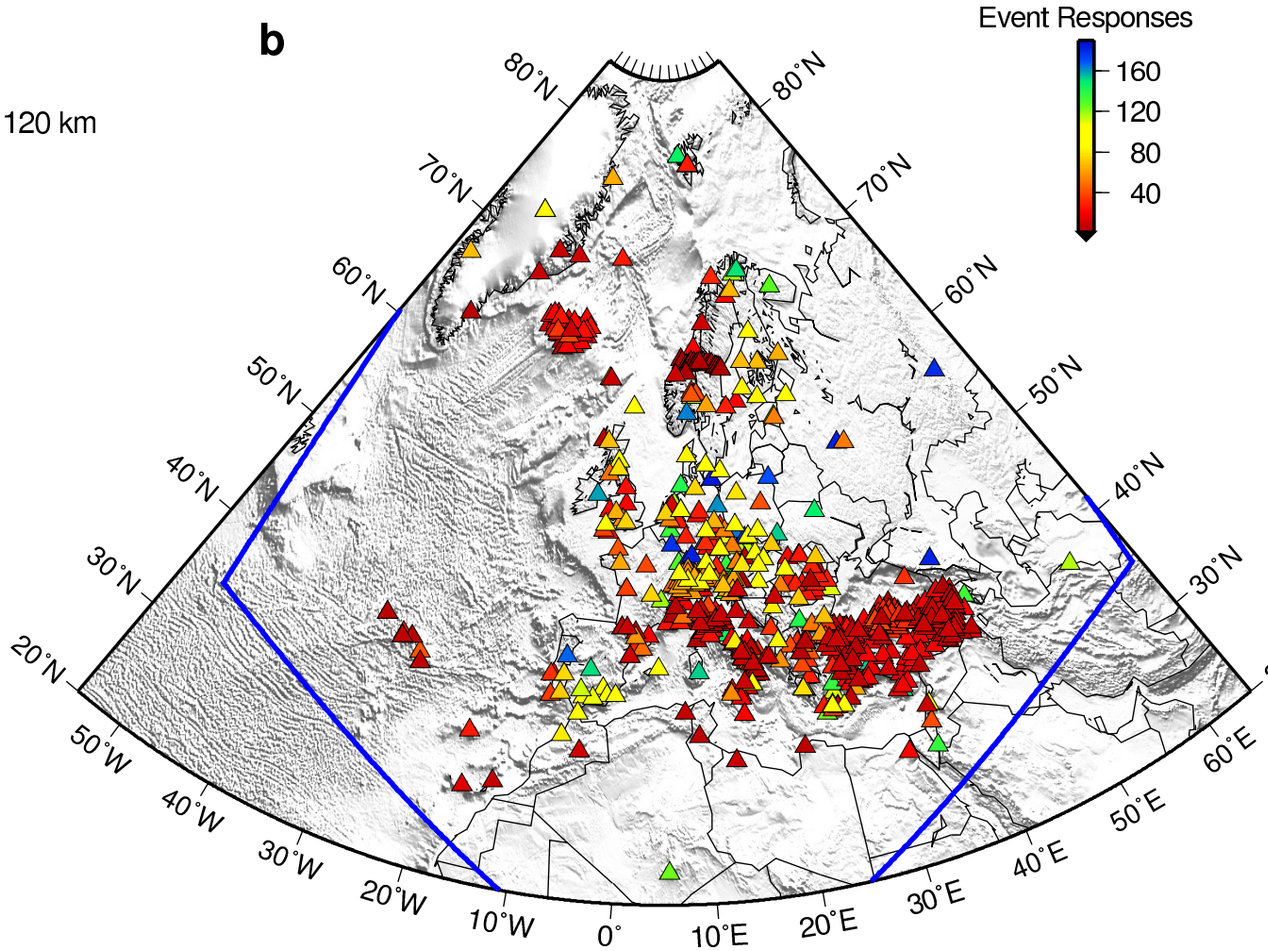
Adjoint Tomography



Adjoint Tomography of Europe

“Big Data”

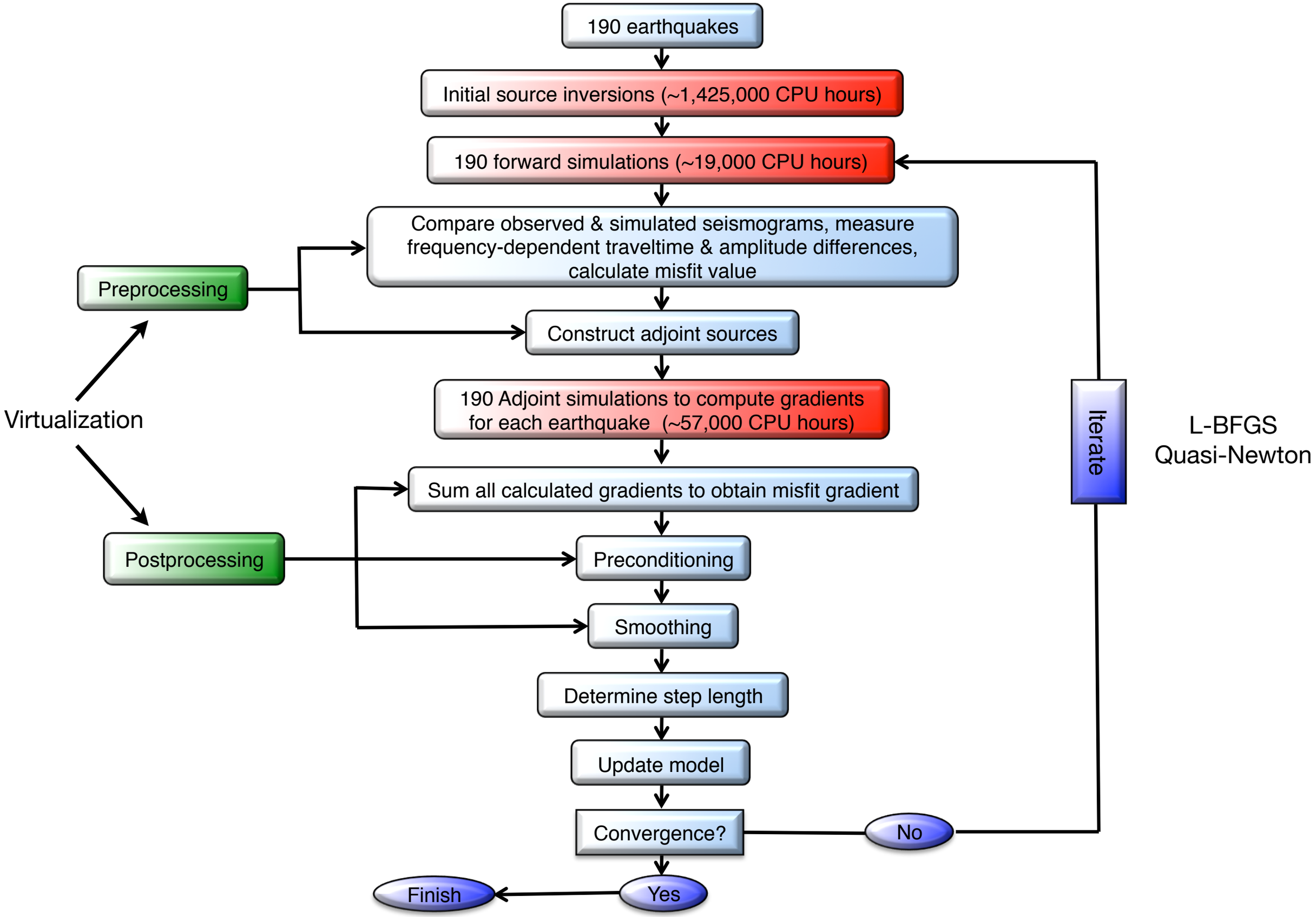


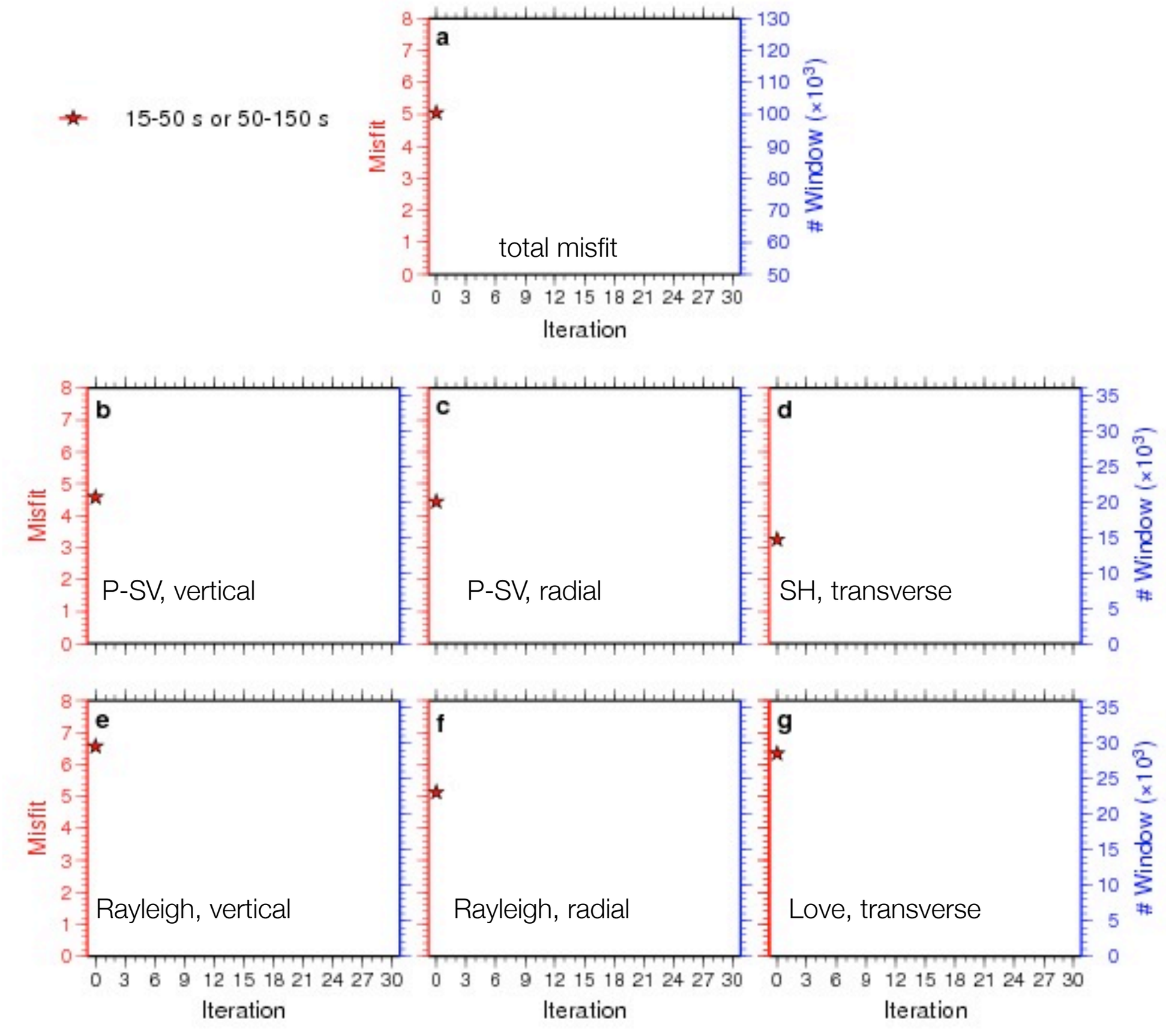


earthquakes	stations	iterations	simulations	CPU hours	measurements
190	745	30	17,100	2.3 million	123,205

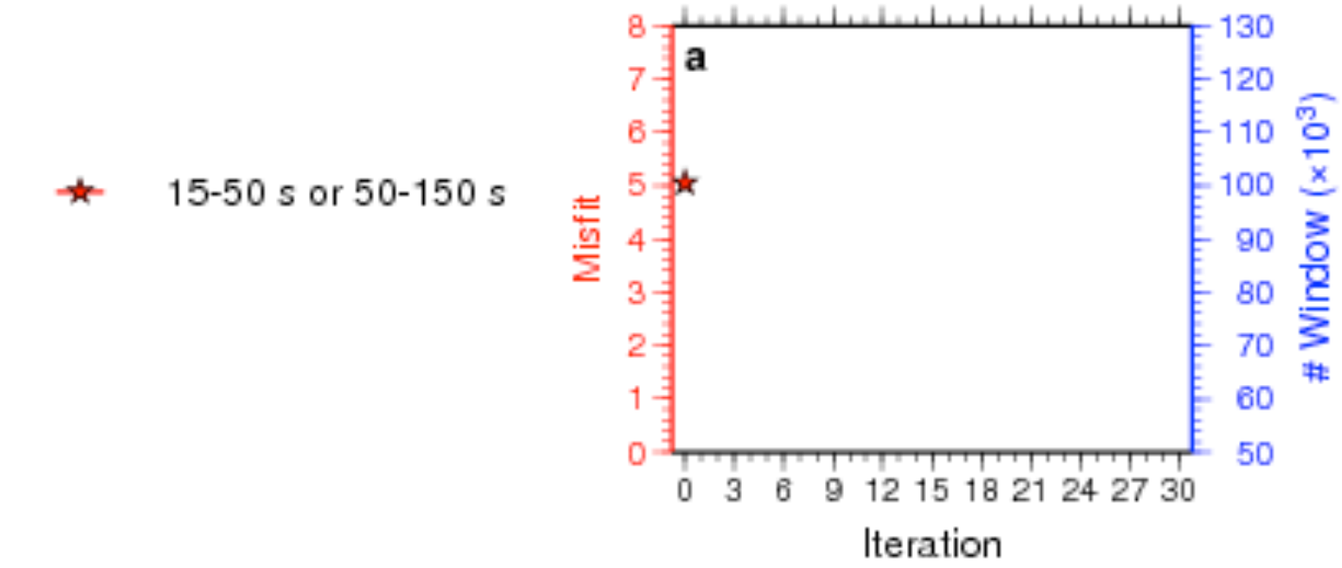
Hejun Zhu

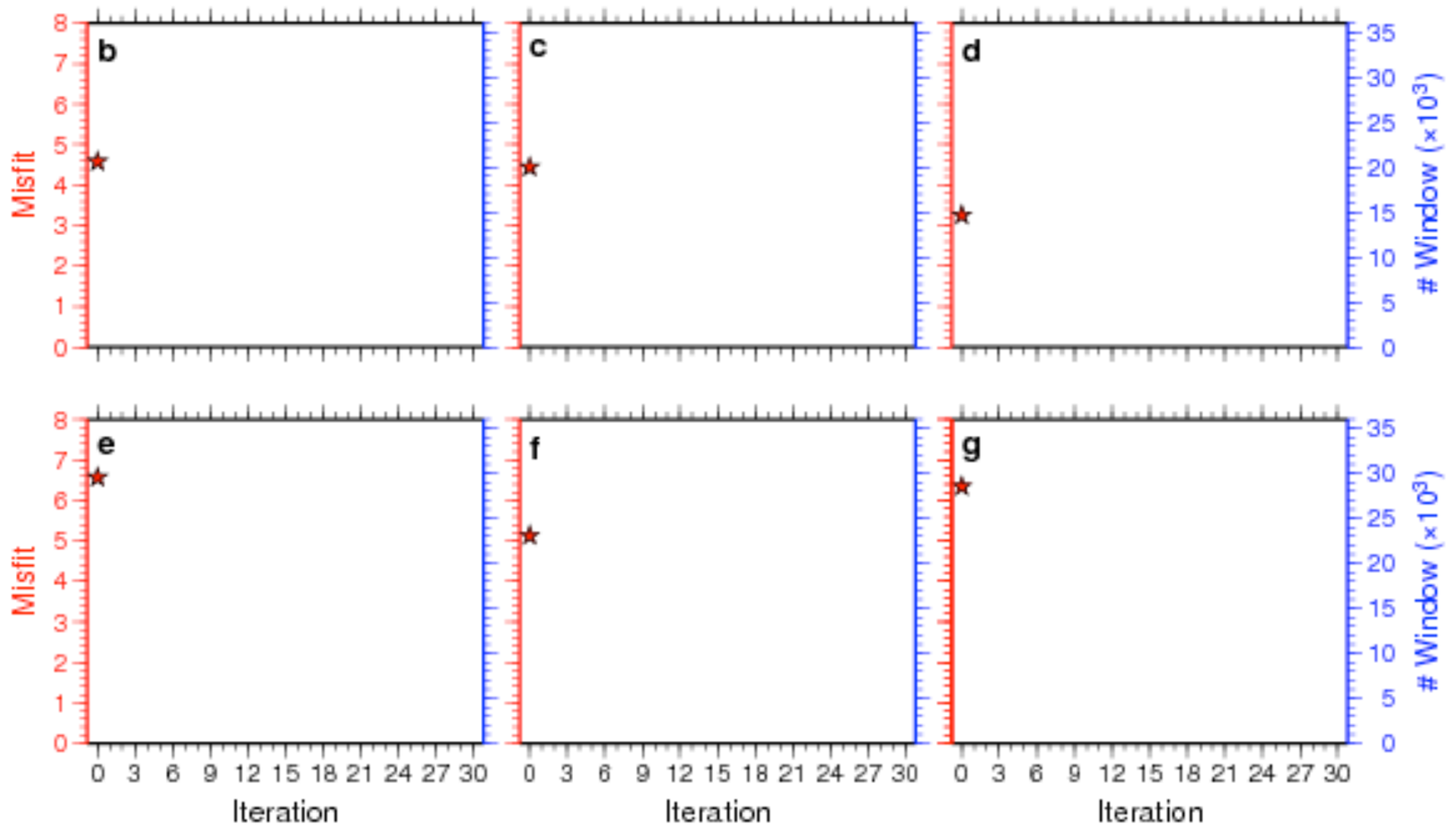
Adjoint Tomography Workflow



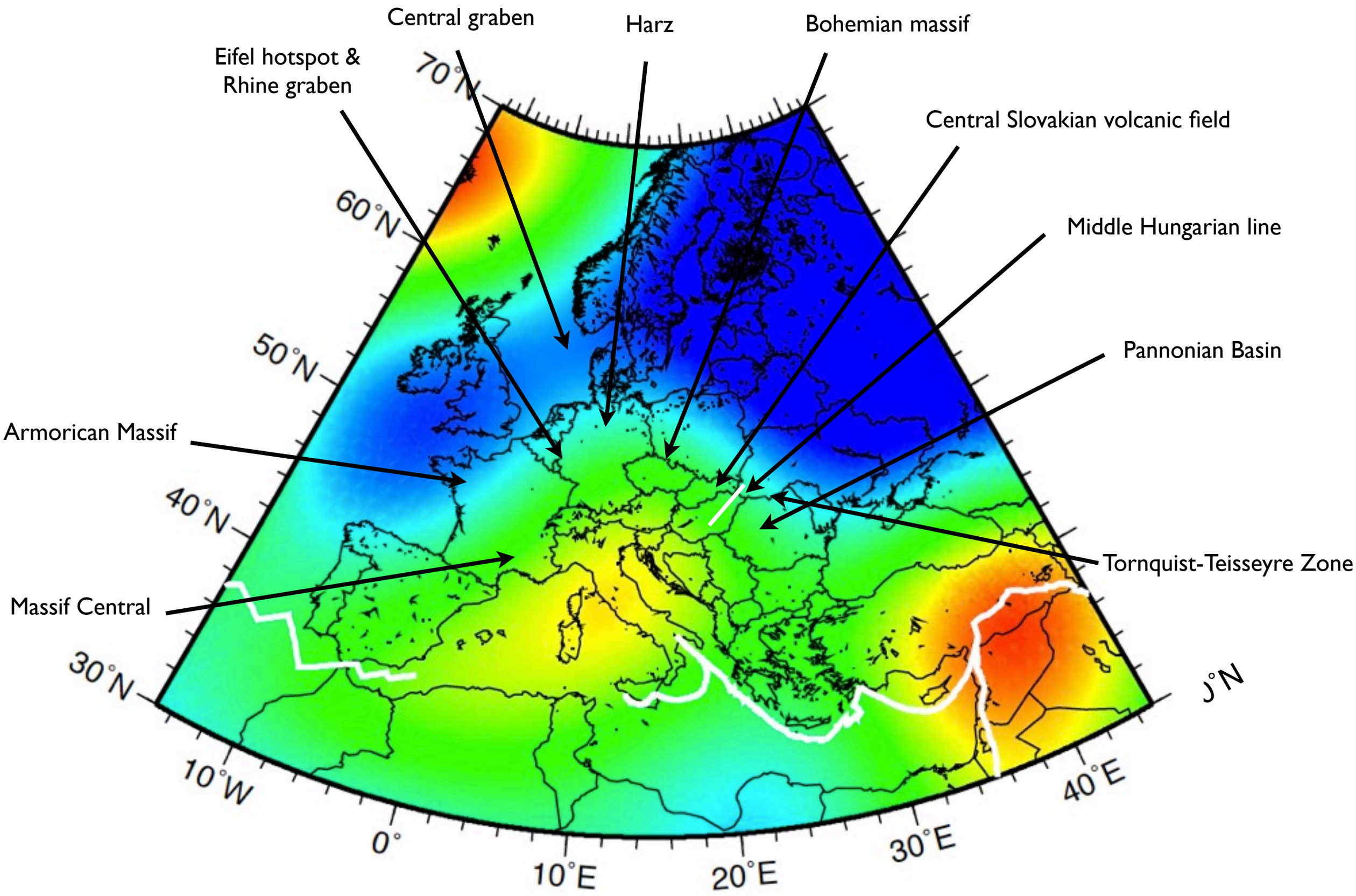

15-50 s or 50-150 s
a
total misfit
Misfit
Window (×10³)
Iteration
b
P-SV, vertical
c
P-SV, radial
d
SH, transverse
e
Rayleigh, vertical
f
Rayleigh, radial
g
Love, transverse

15-50 *s* or 50-150 *s*



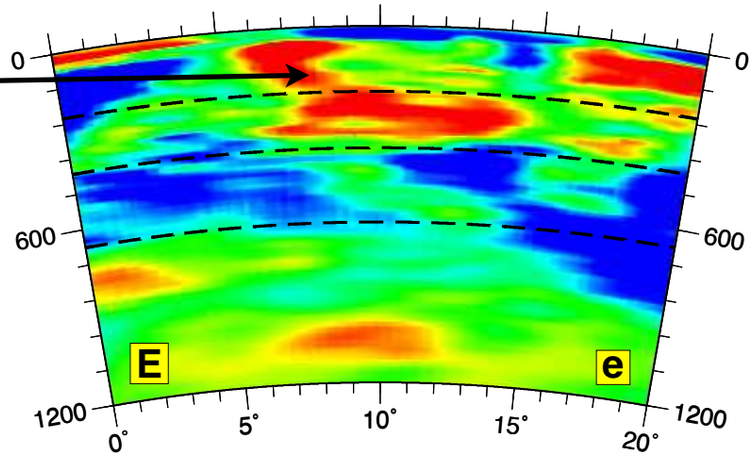


Depth 75 km

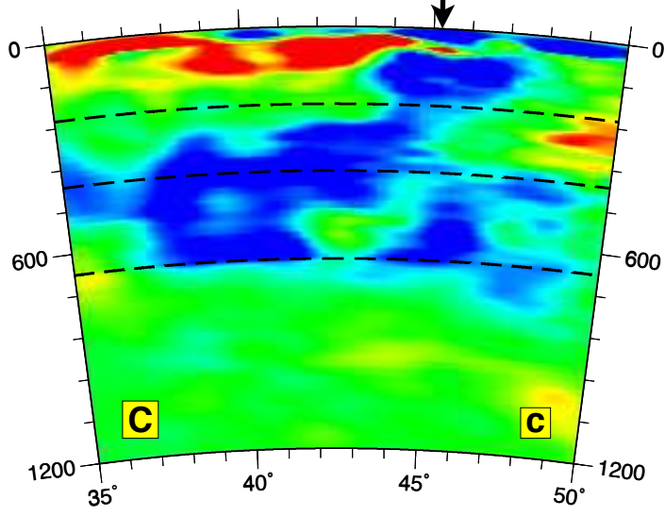


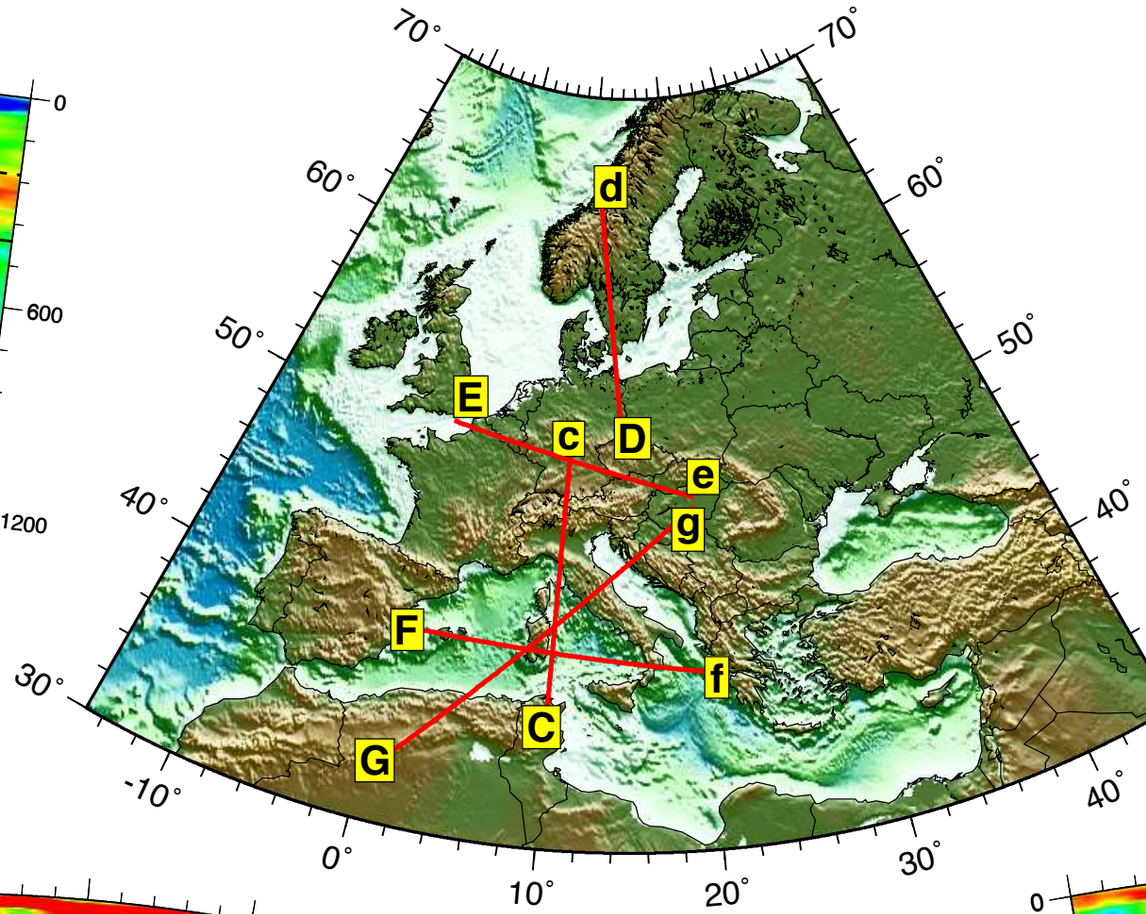
Hejun Zhu

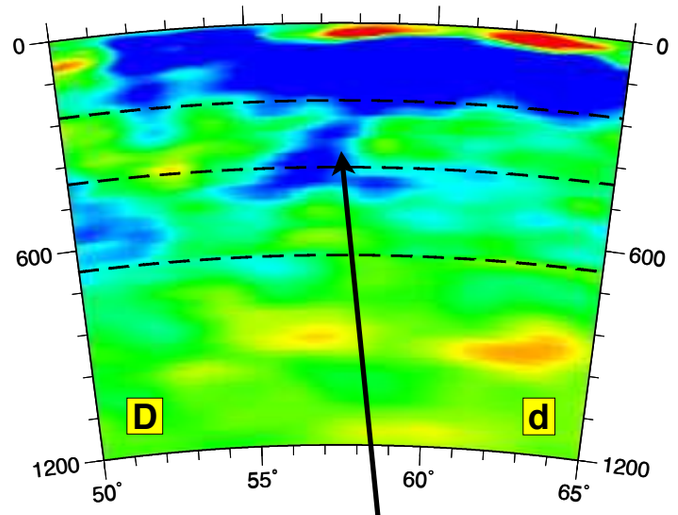
Eifel plume



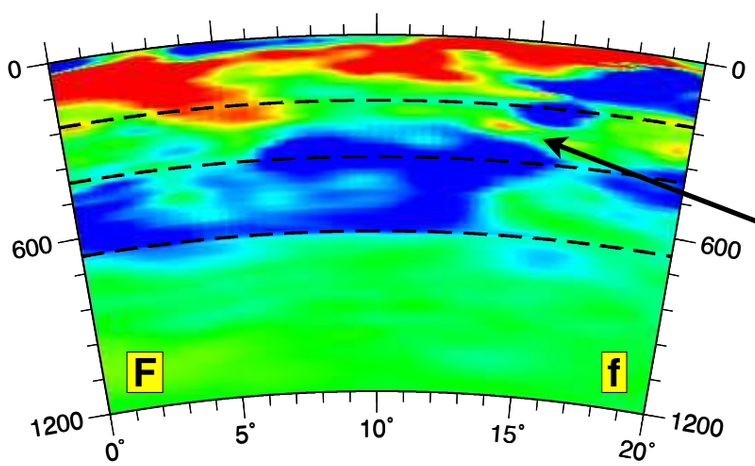
Alps slab



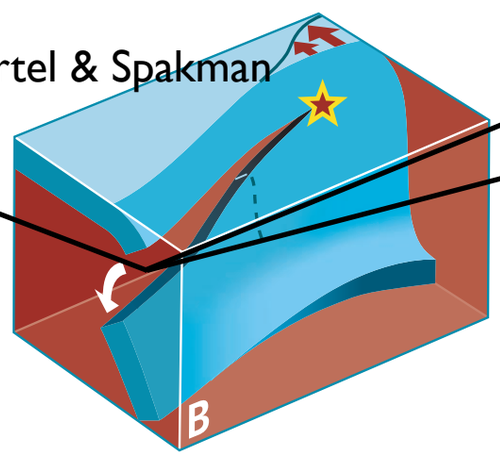


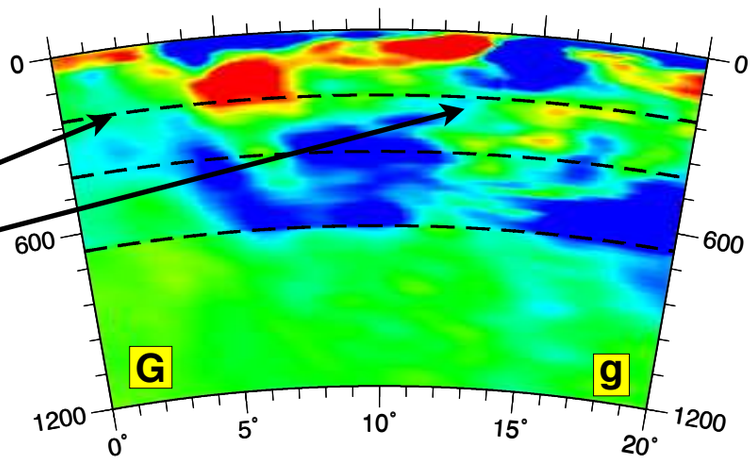


Lithospheric delamination

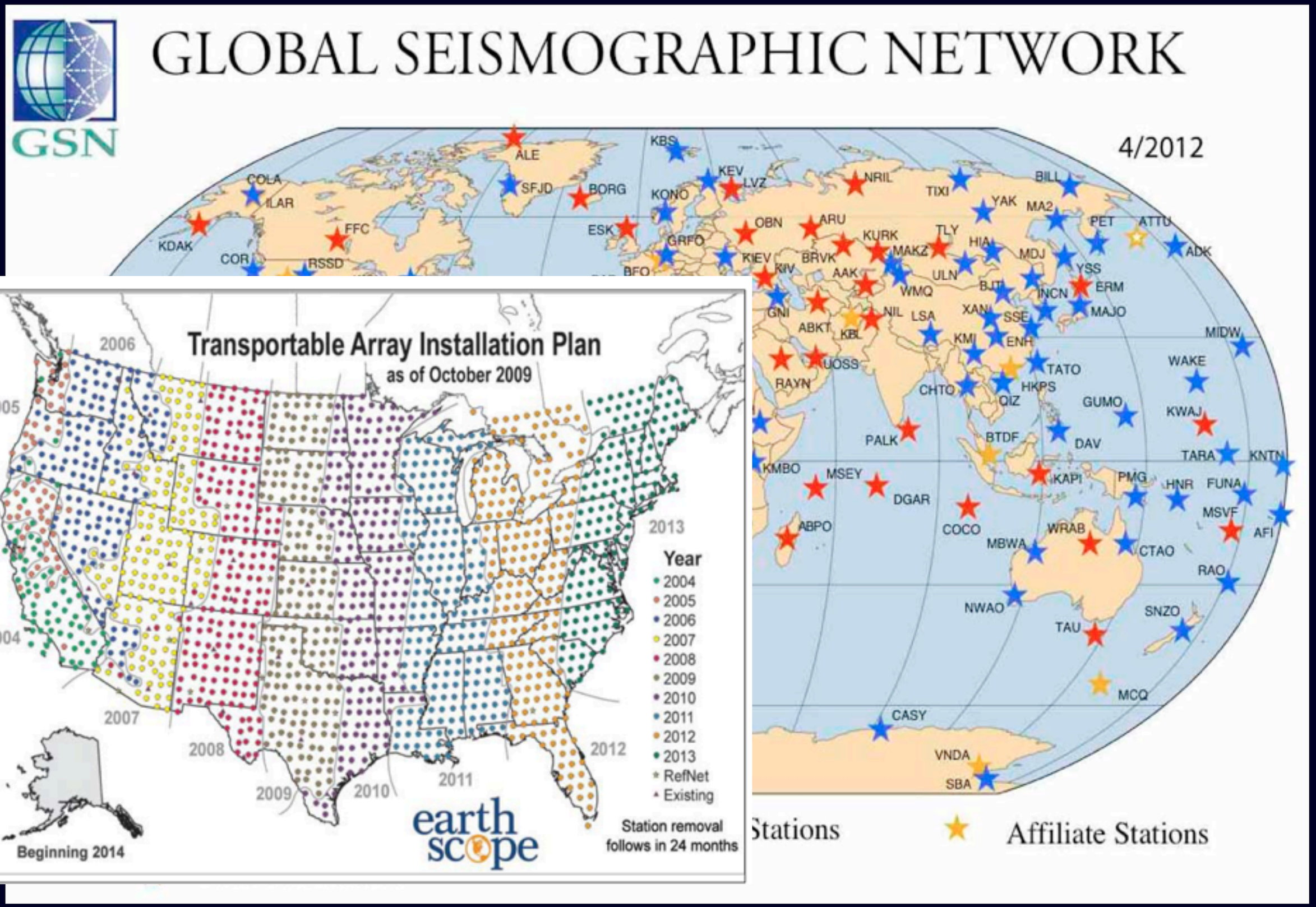


Wortel & Spakman





Global Adjoint Tomography



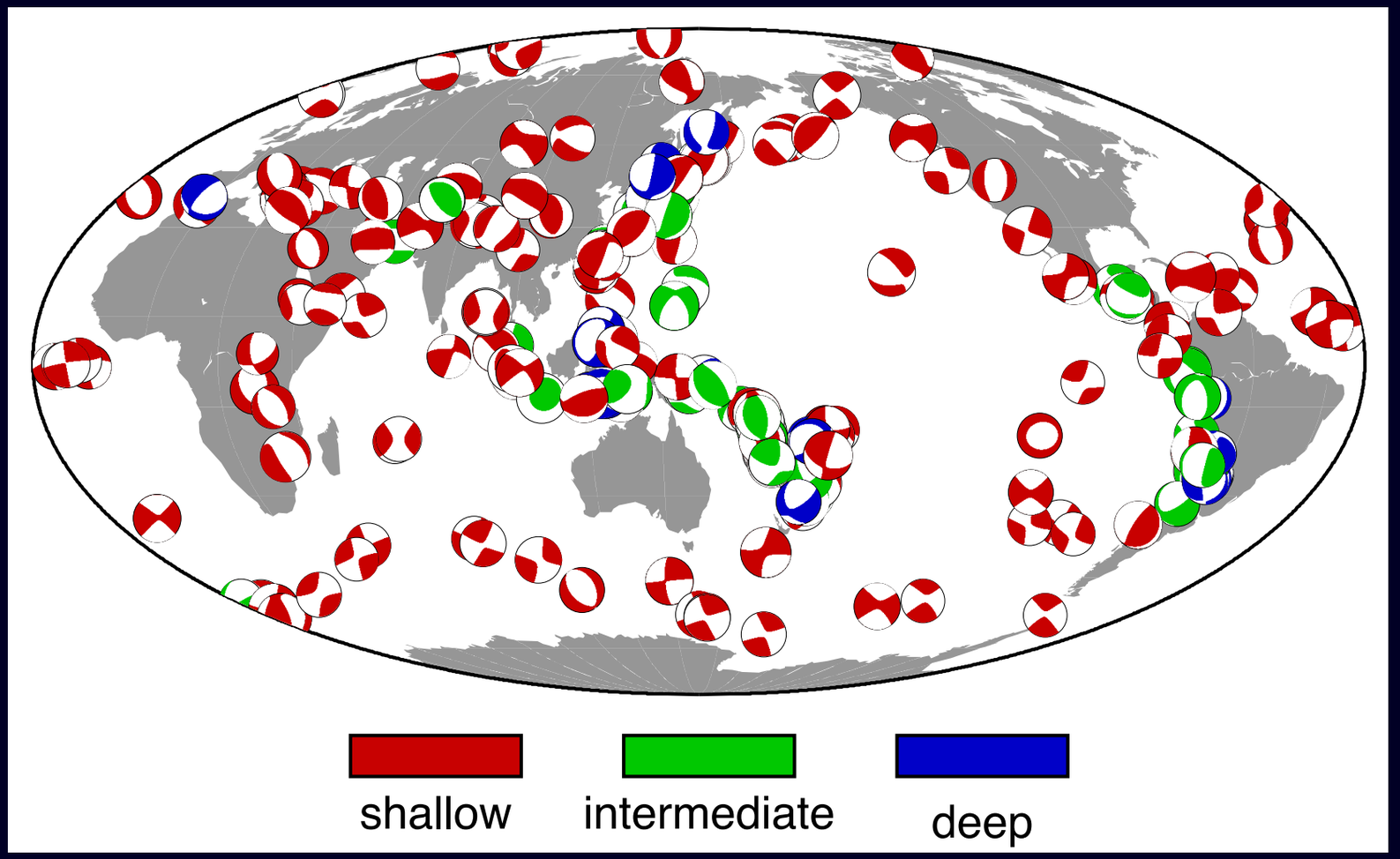
Another Seismometer....

Laptops and cell phones are currently being explored as potential “social” seismographic networks

Earthquake Data Set

255 earthquakes

5.8 ≤ Mw ≤ 7

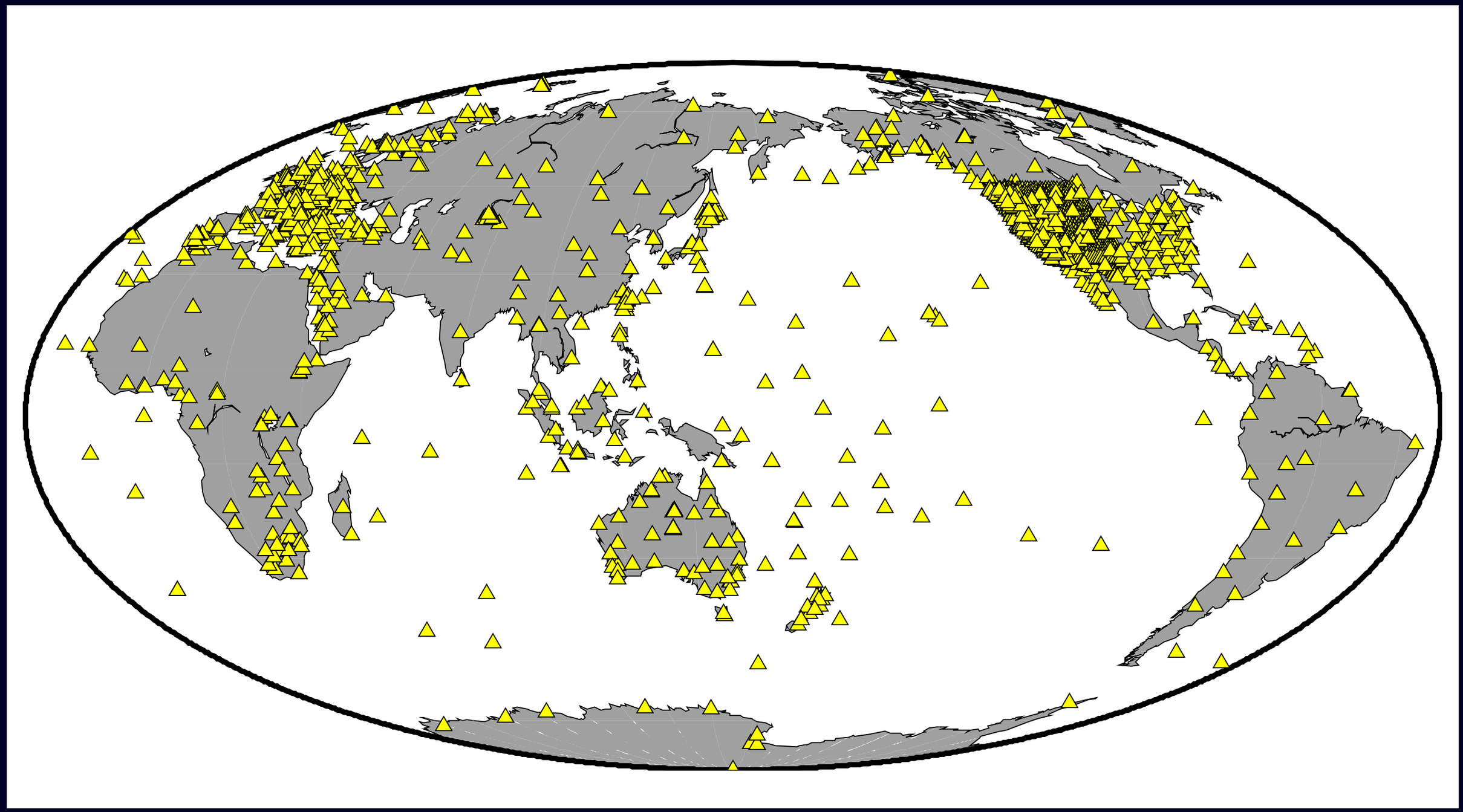


shallow: d≤ 50 km

intermediate: 50 km < d ≤ 300 km

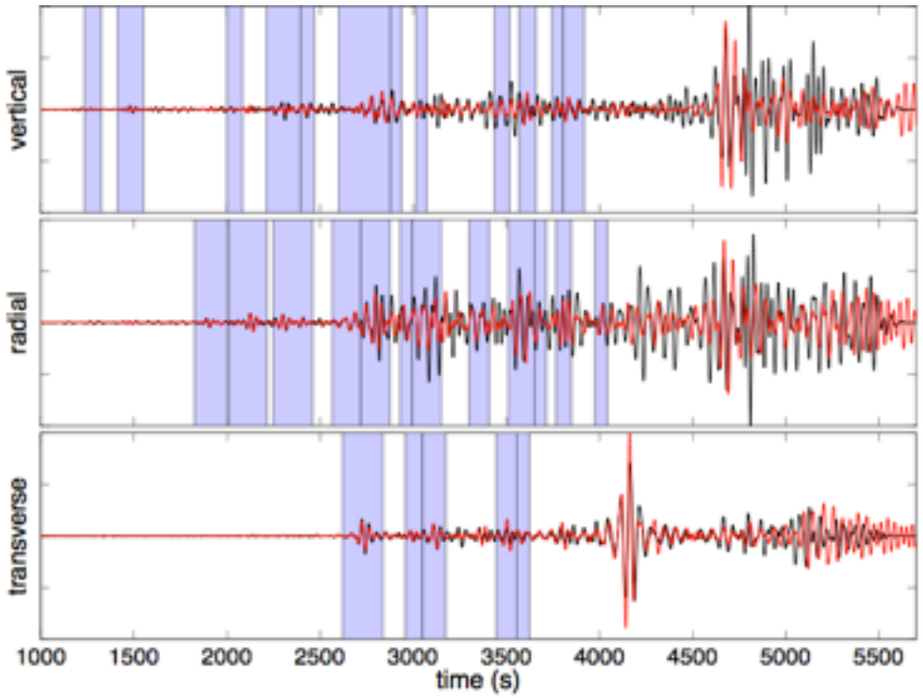
deep: d > 300 km

Seismographic Station Coverage

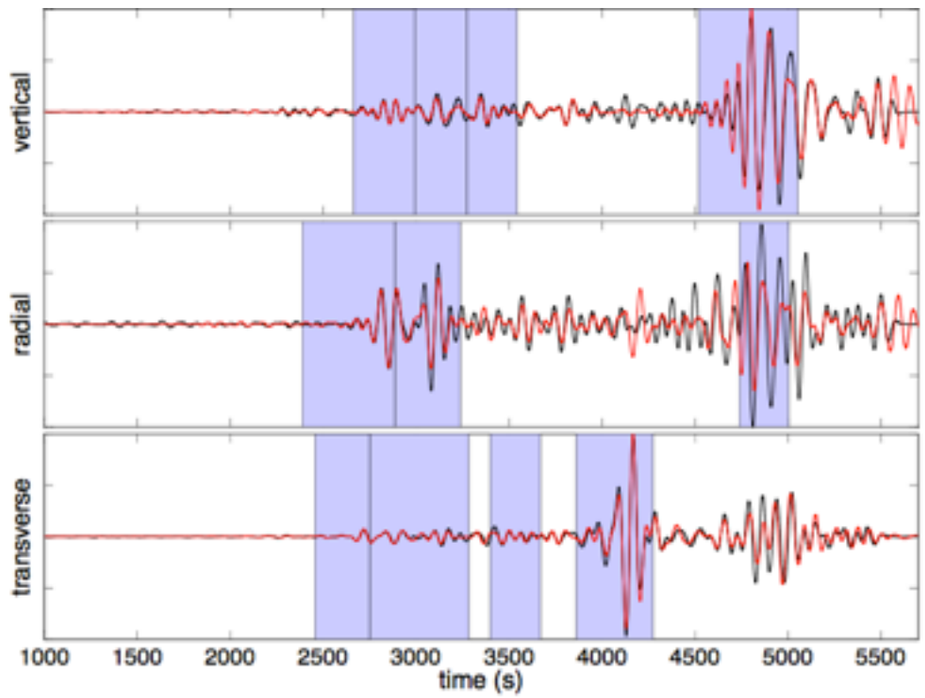


Data Selection

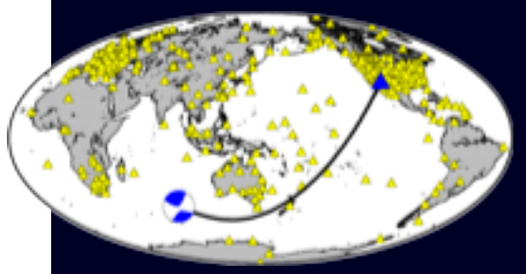
27 s - 60 s



60 s - 120 s



Station: 112A
Δ=165°

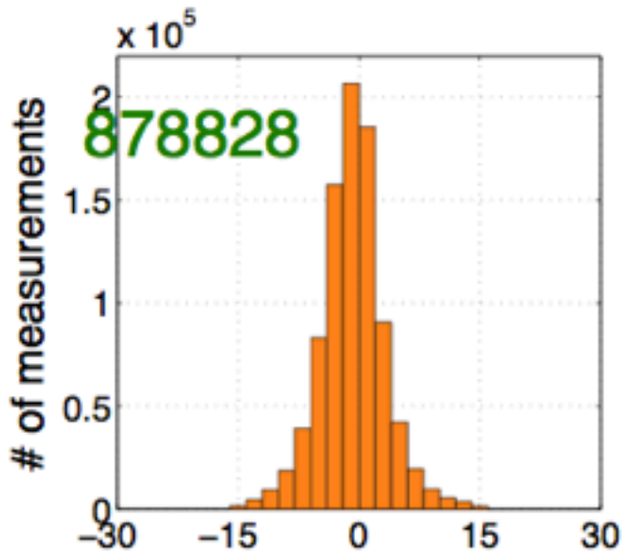
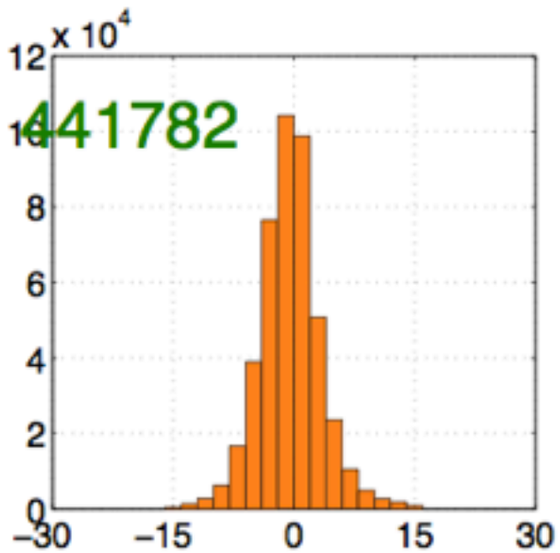
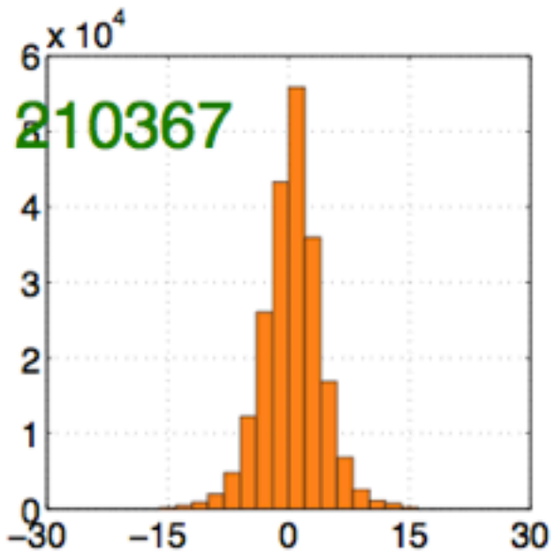
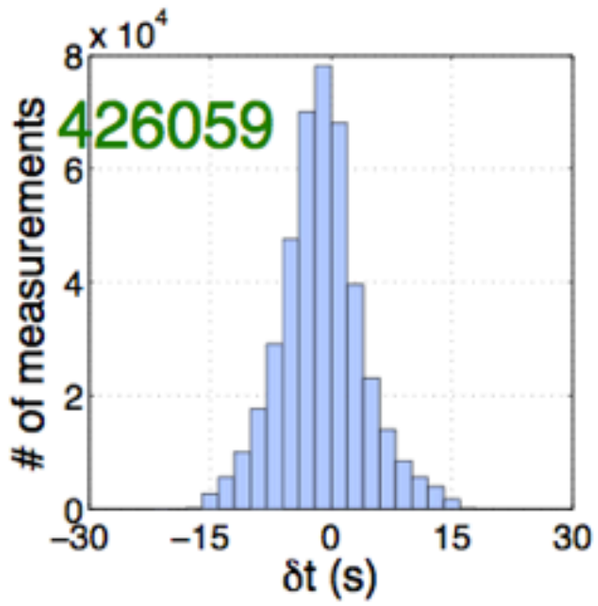
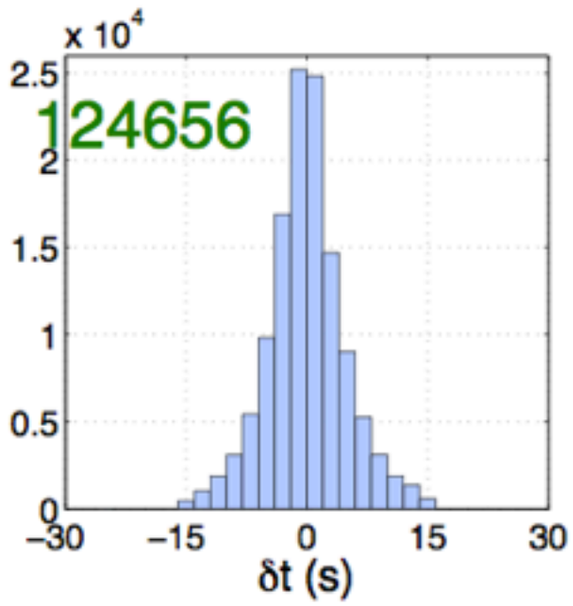
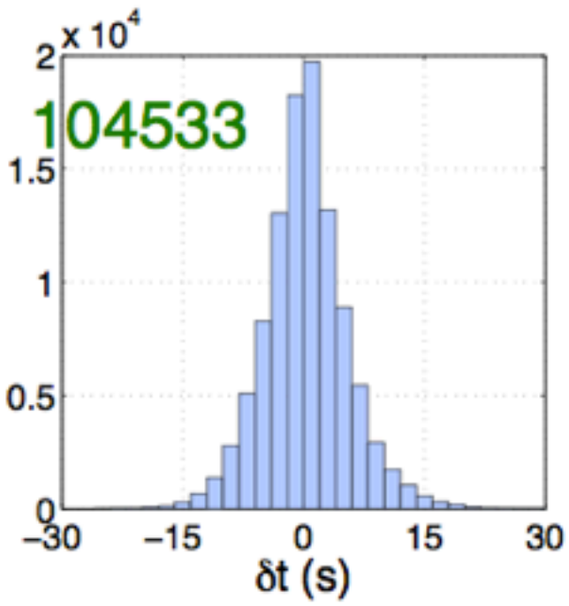


2008, May 31, Mid-Indian Ridge event
Mw=6.4, depth=6.5 km

Goal on Titan: 9 s shortest period

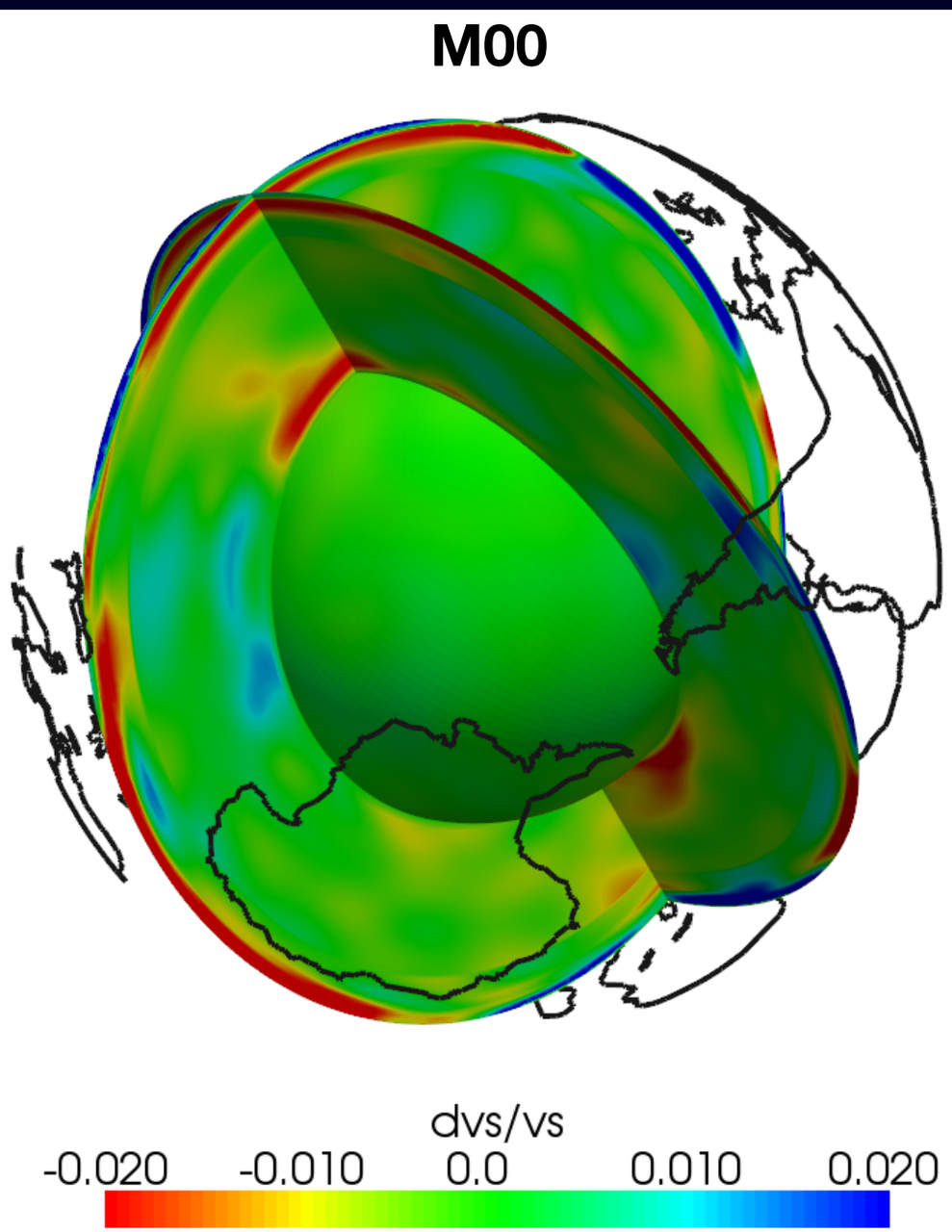
window selection:
FLEXWIN (Maggi et al. 2009)

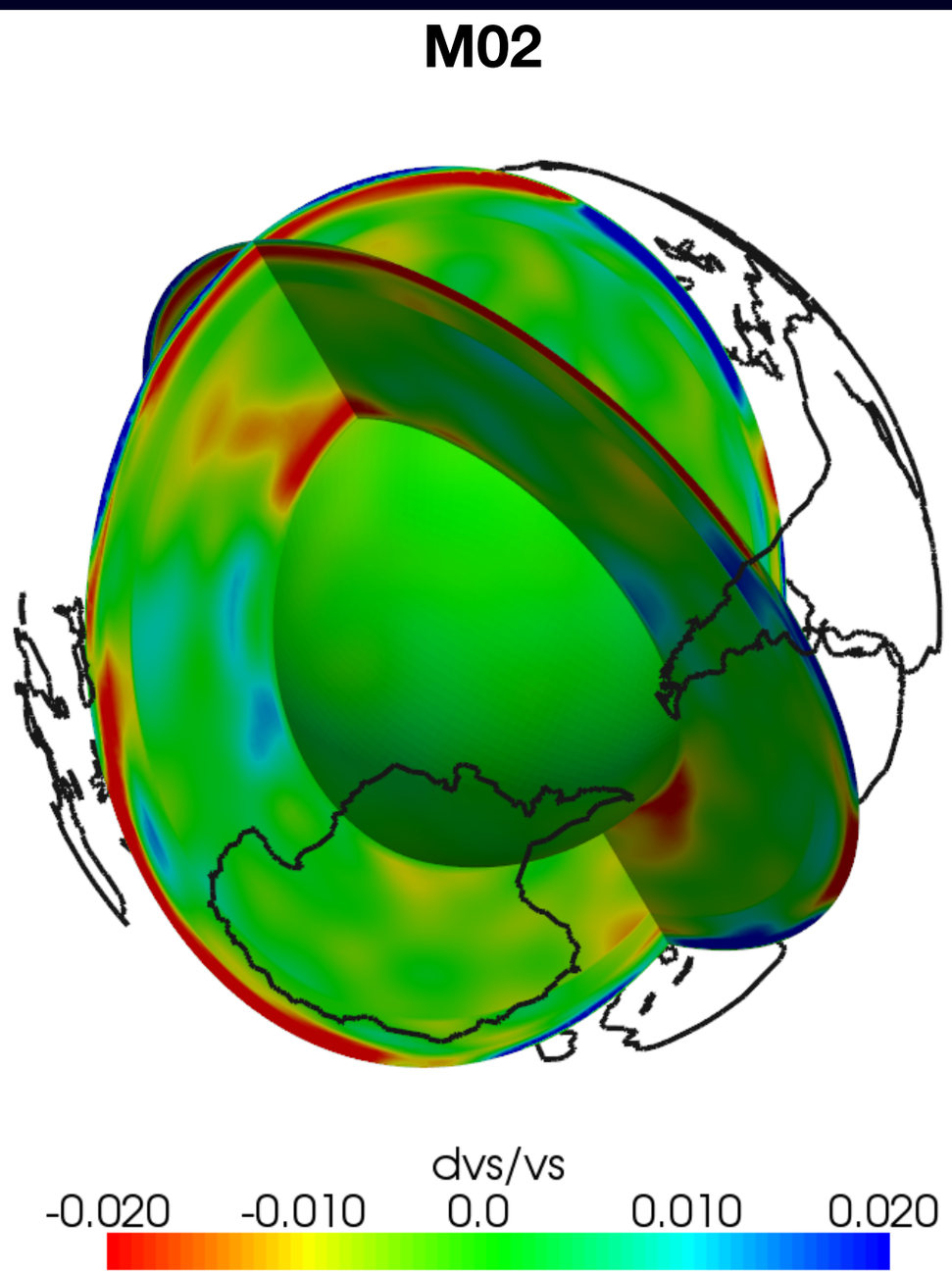
Measurements

	vertical	radial	transverse
27 - 60 s			
60 - 120 s			

~2.2 million measurements

Second Generation Model





Conclusions & Future Work

Software Development:

- GPU versions of production software finished
- Excellent weak and strong scaling

see SC'12 talk by Rietmann et al. , Tuesday 4-4:30, 355-EF

- Initiating a collaboration with Intel to port to MIC
- Initiating a collaboration with IBM focused on "big data" and workflows

Adjoint Tomography:

- Finished adjoint tomography of Europe
- Initiated adjoint tomography of Southeast Asia
- Performed two preliminary low-resolution global iterations
  - INCITE allocation on ORNL “Titan” starting January 2013

Big data, Workflow & Virtualization Issues:

- Data assimilation requires massive data processing & analysis
- Preconditioning & smoothing as part of L-BFGS
- Exploring data and model formats to accommodate I/O

  NetCDF, PnetCDF, HDF5 and ADIOS

- Model analysis, visualization and utilization