

Spectral-Element Simulations of Earthquakes at Global and Regional Scales

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The Spectral-Element Method



- Developed 15 years ago in Computational Fluid Dynamics
- Accuracy of a pseudospectral method
- Flexibility of a finite-element method

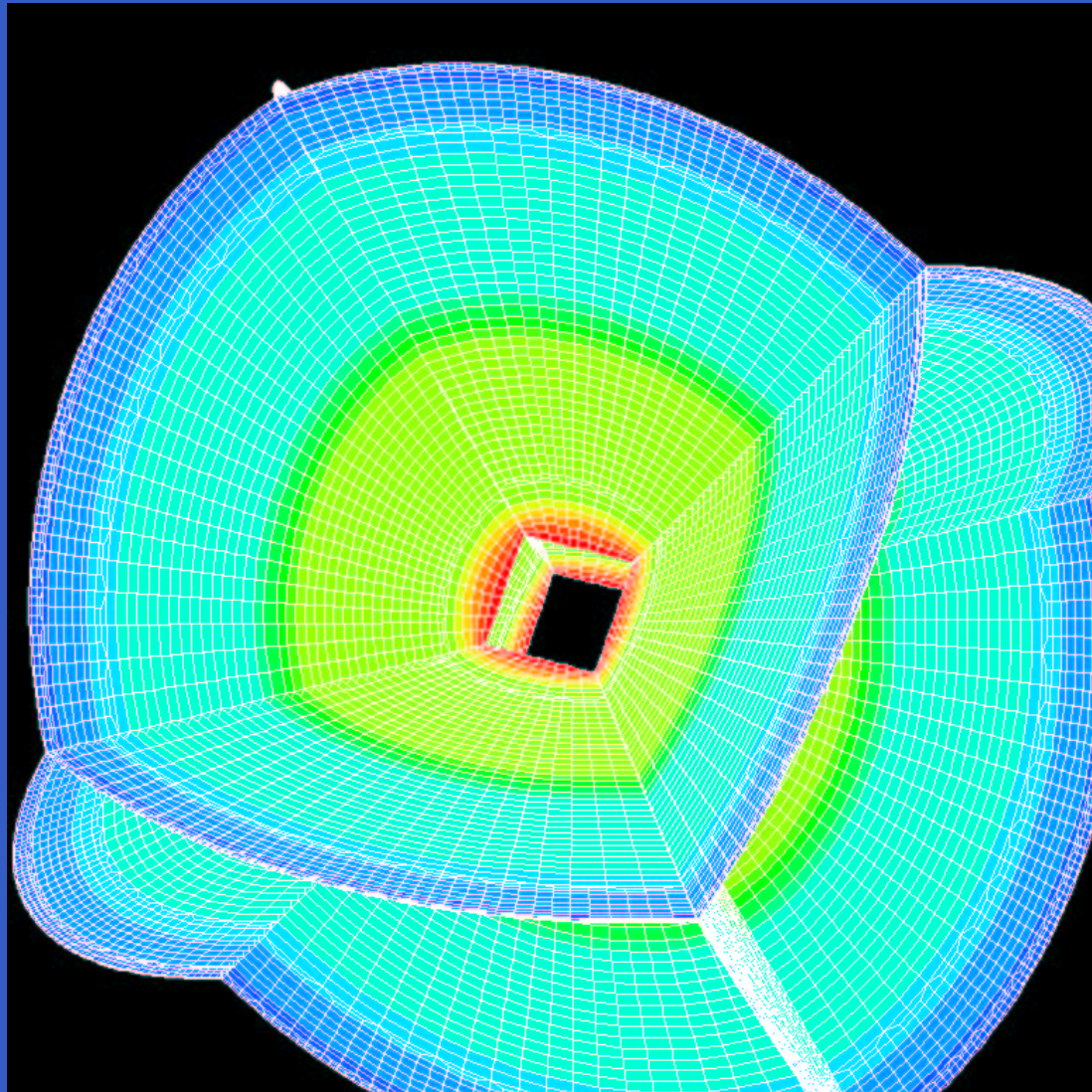
Global Seismology

The Challenge of the Globe

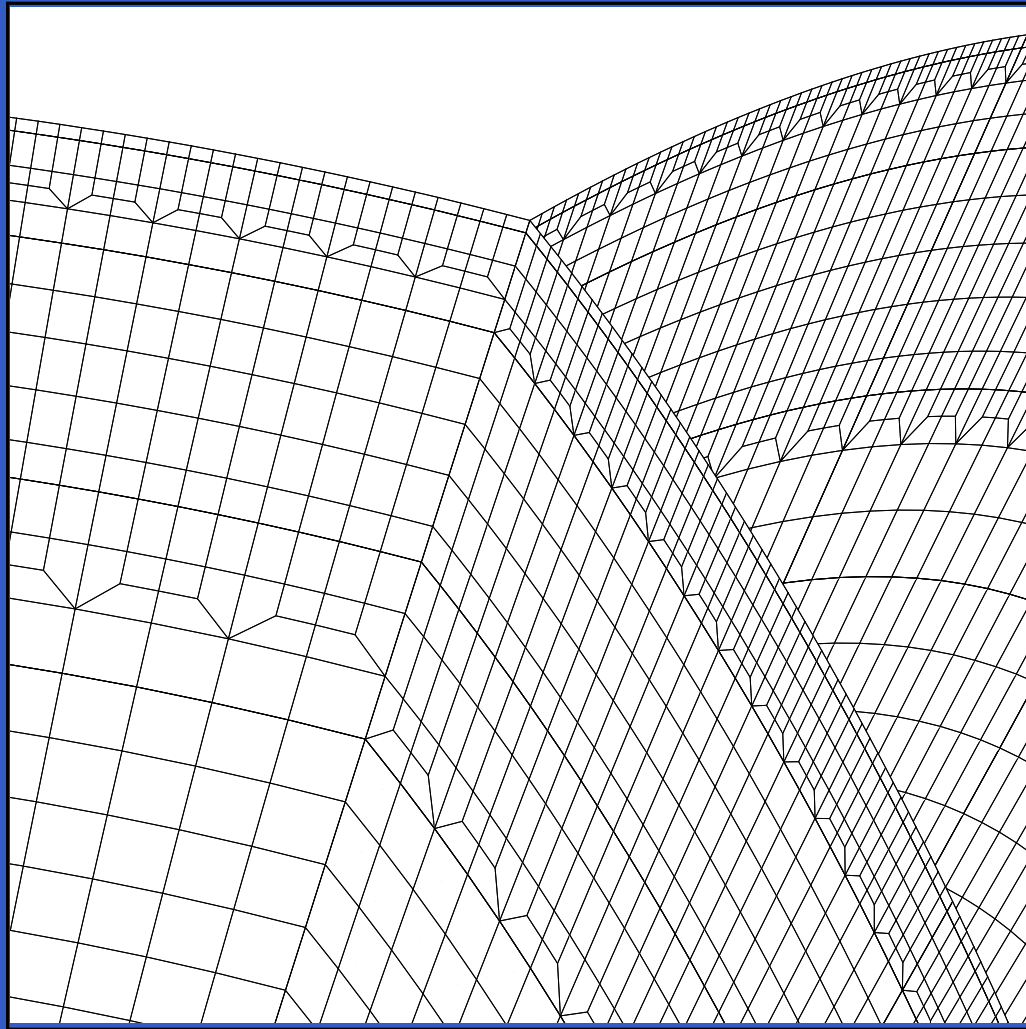


- A slow, thin, highly variable crust
- Sharp radial discontinuities
- Fluid-solid boundaries
- Anisotropy
- Attenuation
- Ellipticity, topography & bathymetry
- Rotation
- Self-gravitation

The Mesh



Mesh Close-Up



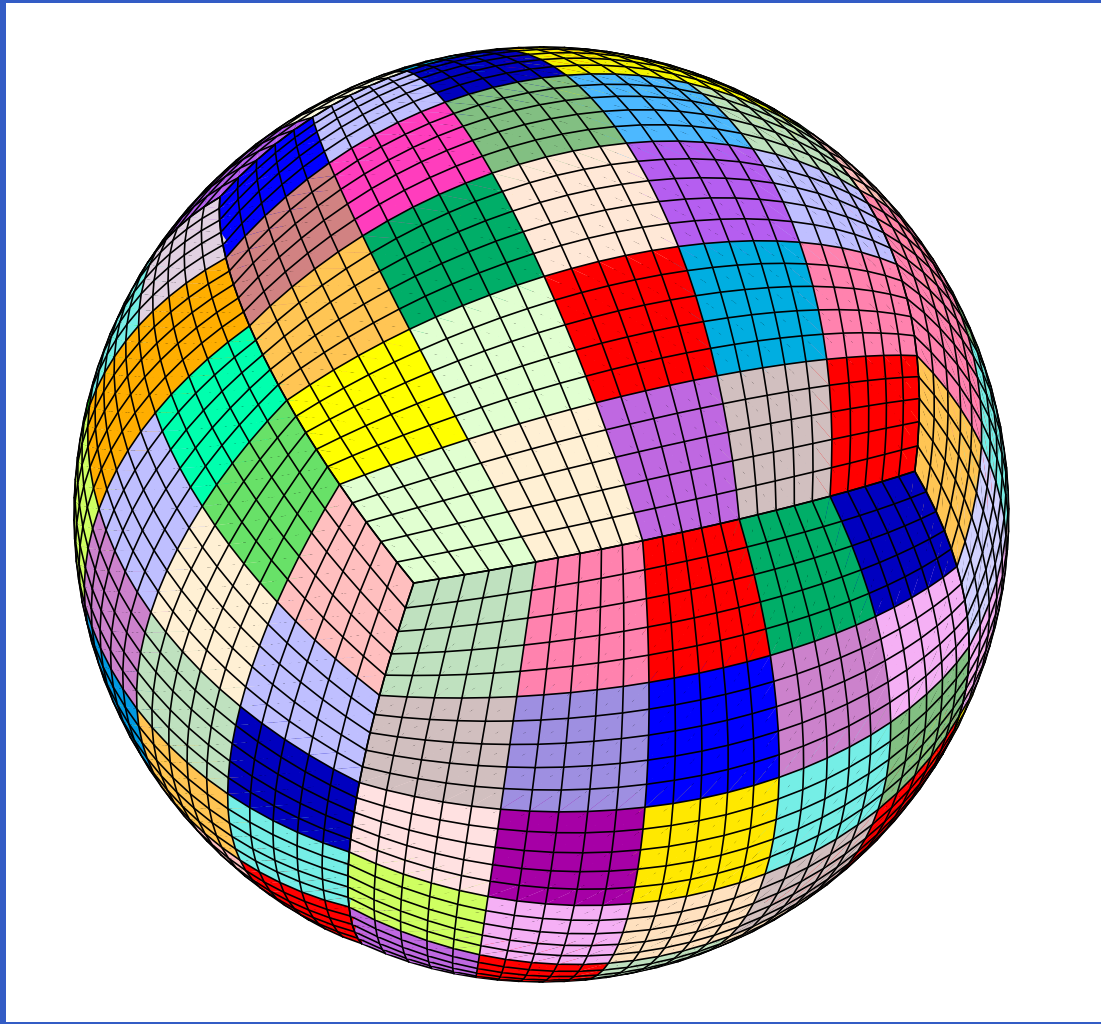
The Seismo Lab Beowulf



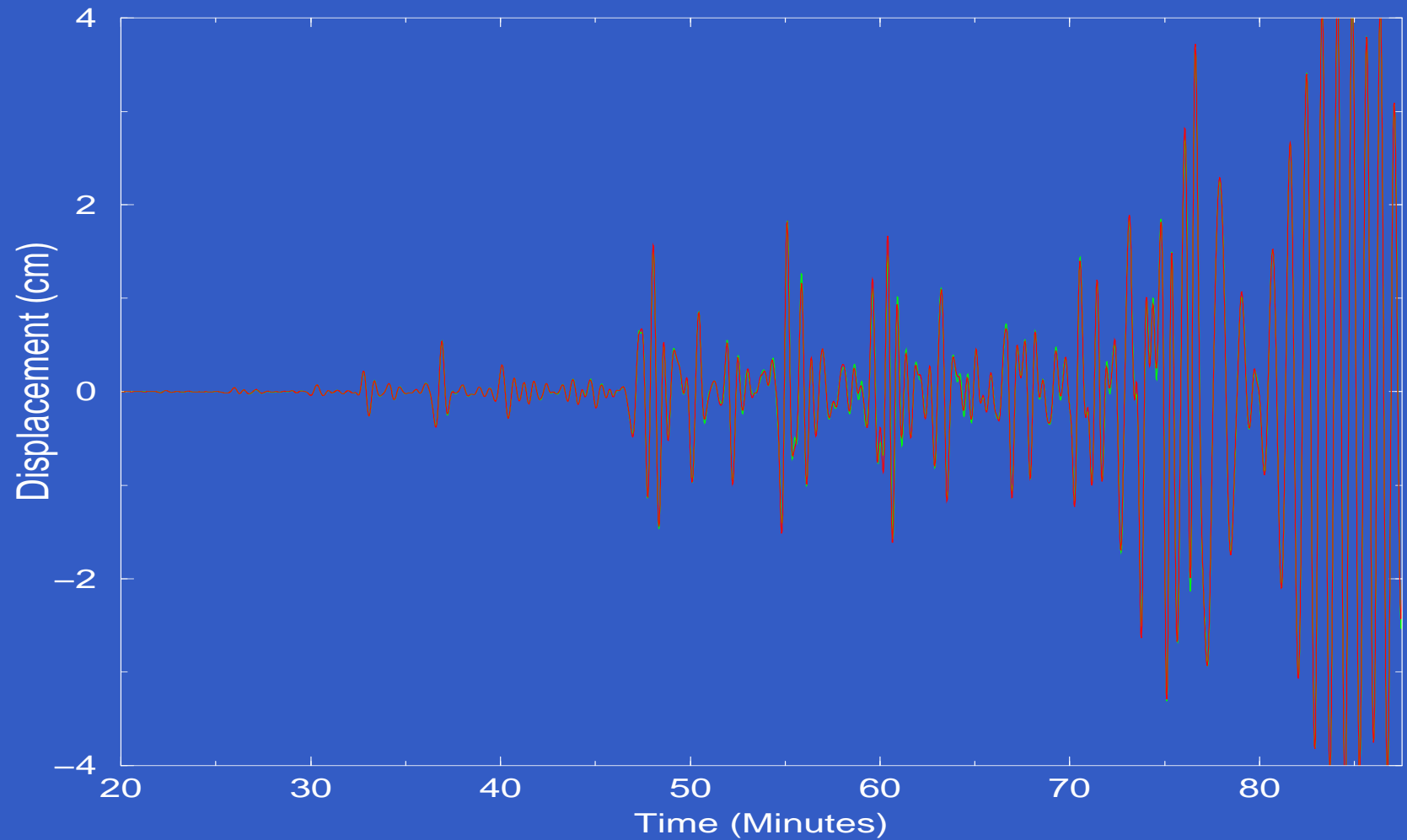
- 312 processors
- 156 GB of RAM
- 733 MHz Pentium III
- 133 MHz Tyan boards
- CISCO switch
- Linux OS
- MPICH communications

Next: EarthSimulator
(with Seiji Tsuboi)

Slicing the Globe

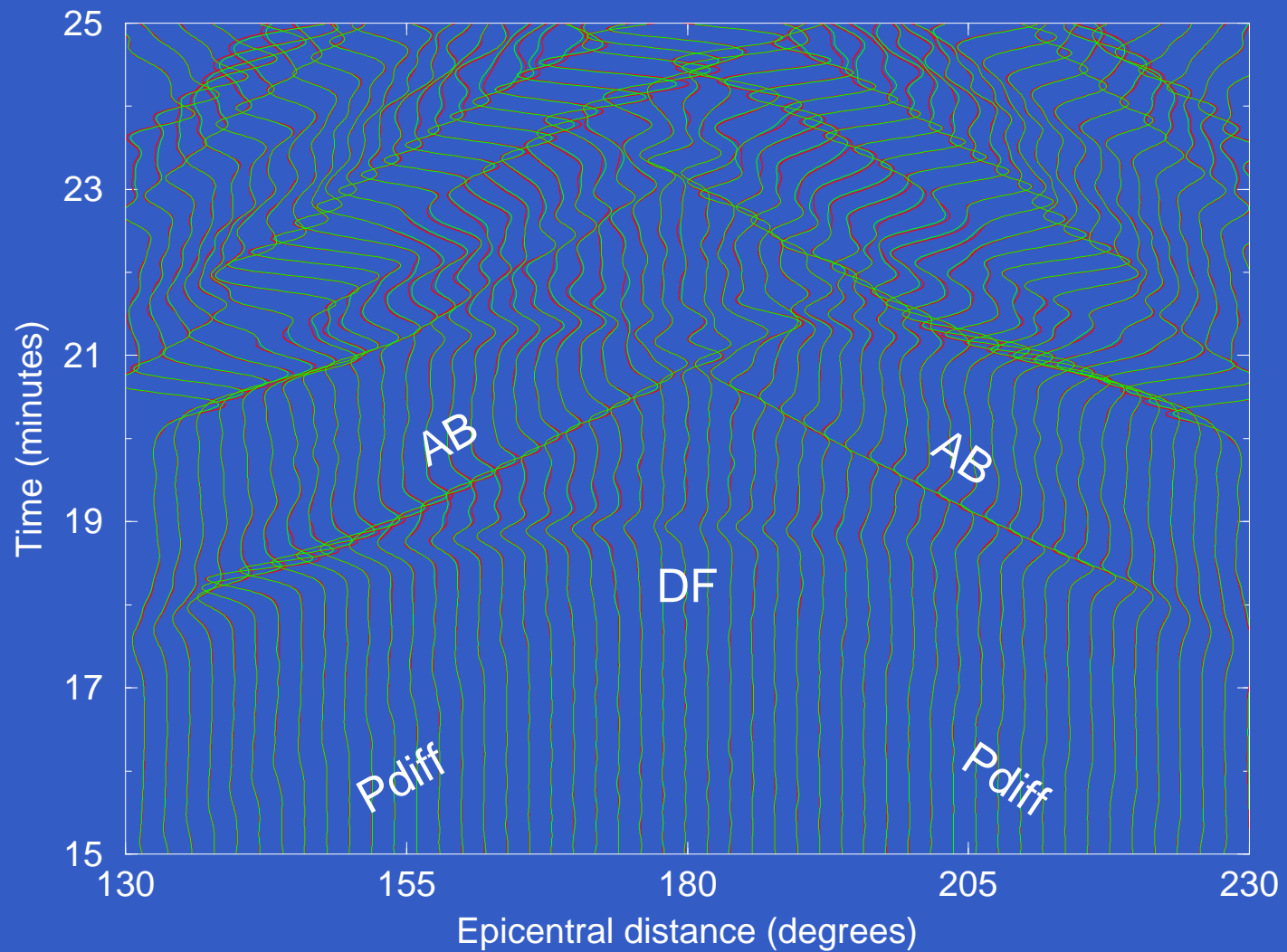


Antipode (Transverse)

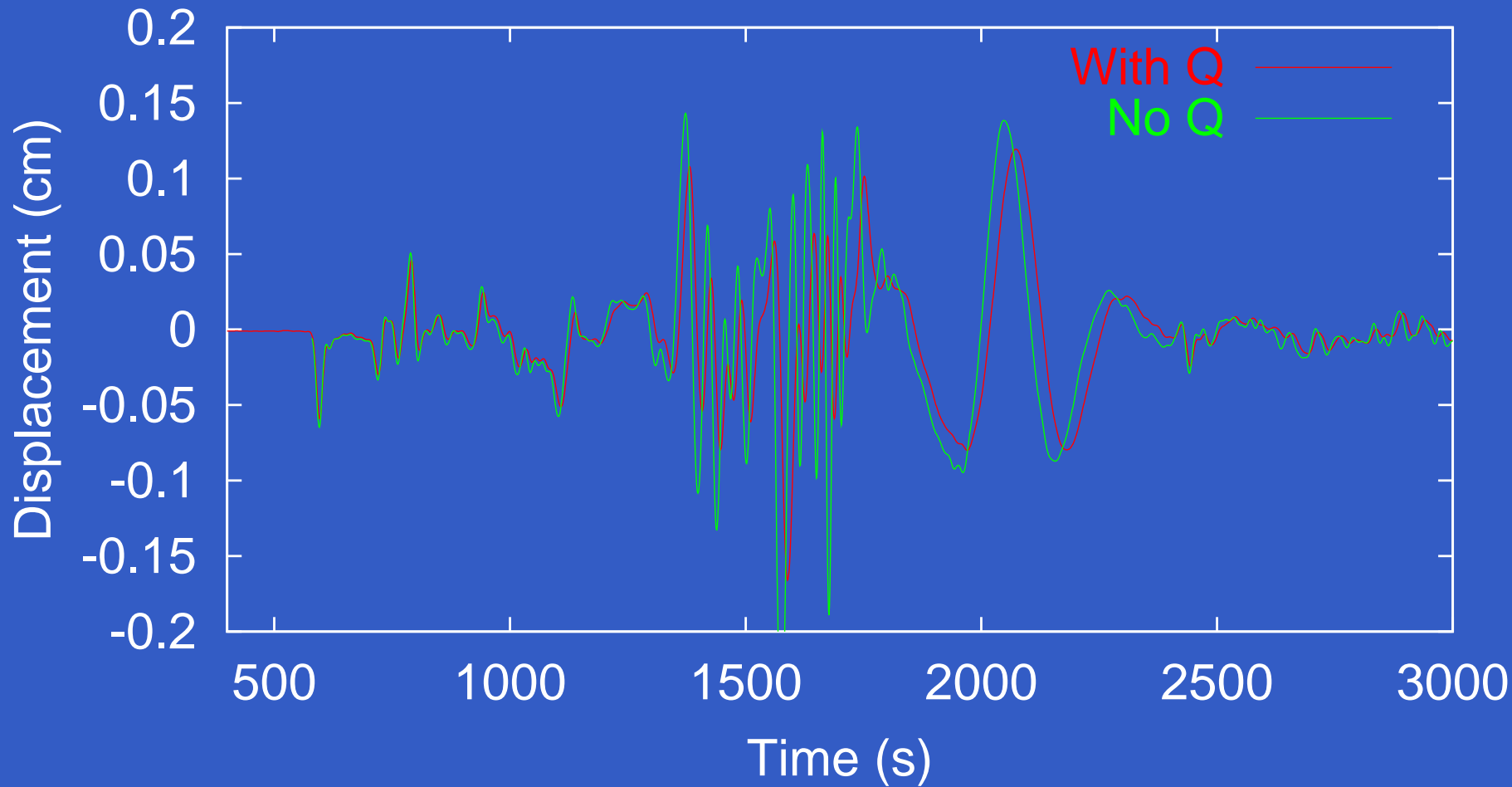


Komatitsch & Tromp (GJI, 149, 390-412, 2002)

PKP Arrivals

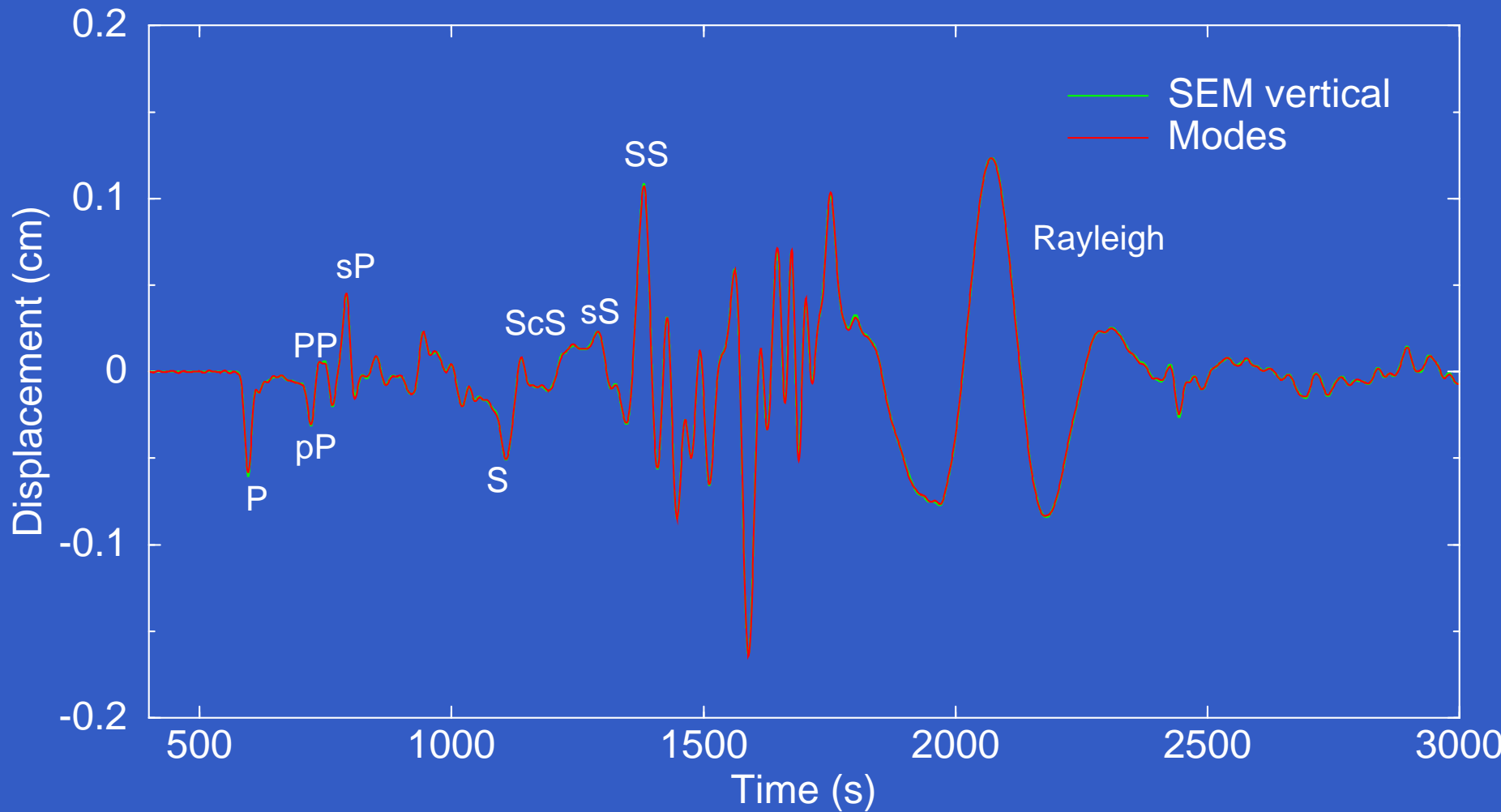


Effect of Attenuation



Komatitsch & Tromp (GJI, 149, 390-412, 2002)

Accuracy of Attenuation

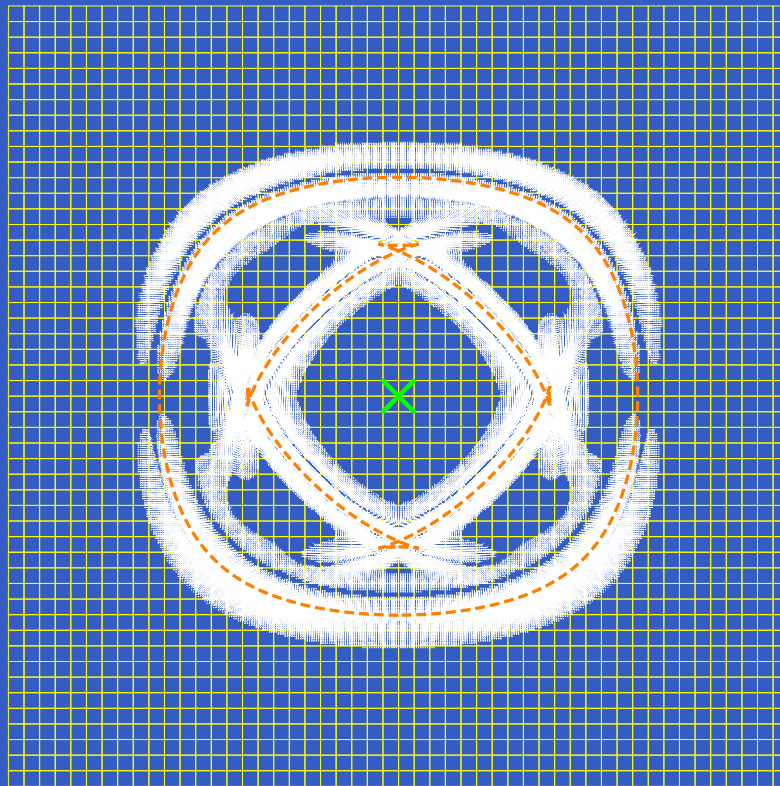


Komatitsch & Tromp (GJI, 149, 390-412, 2002)

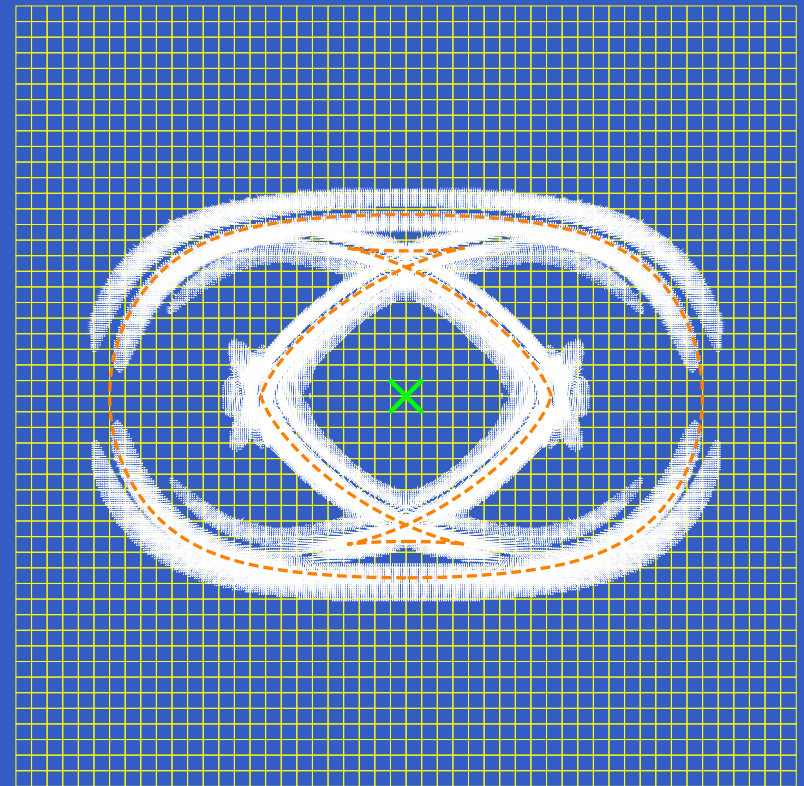
Anisotropic Crystals



Anisotropy is easy: $\mathbf{T} = \mathbf{c} : \nabla \mathbf{s}$

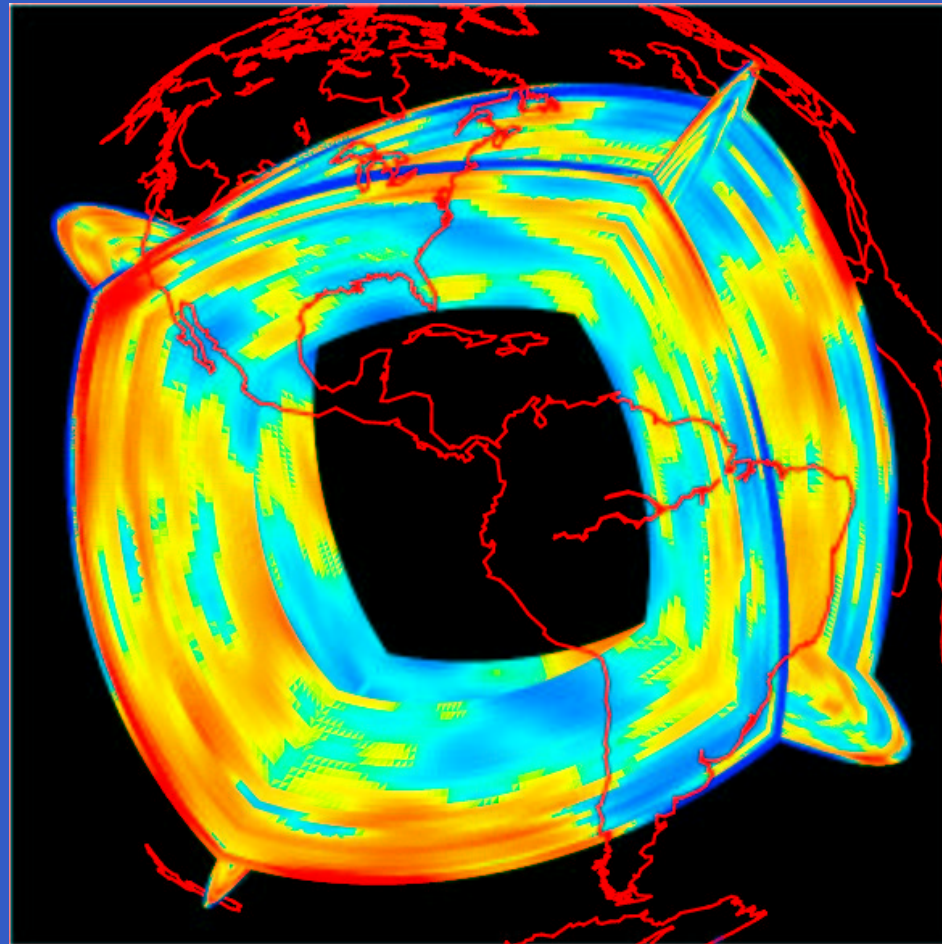


Apatite



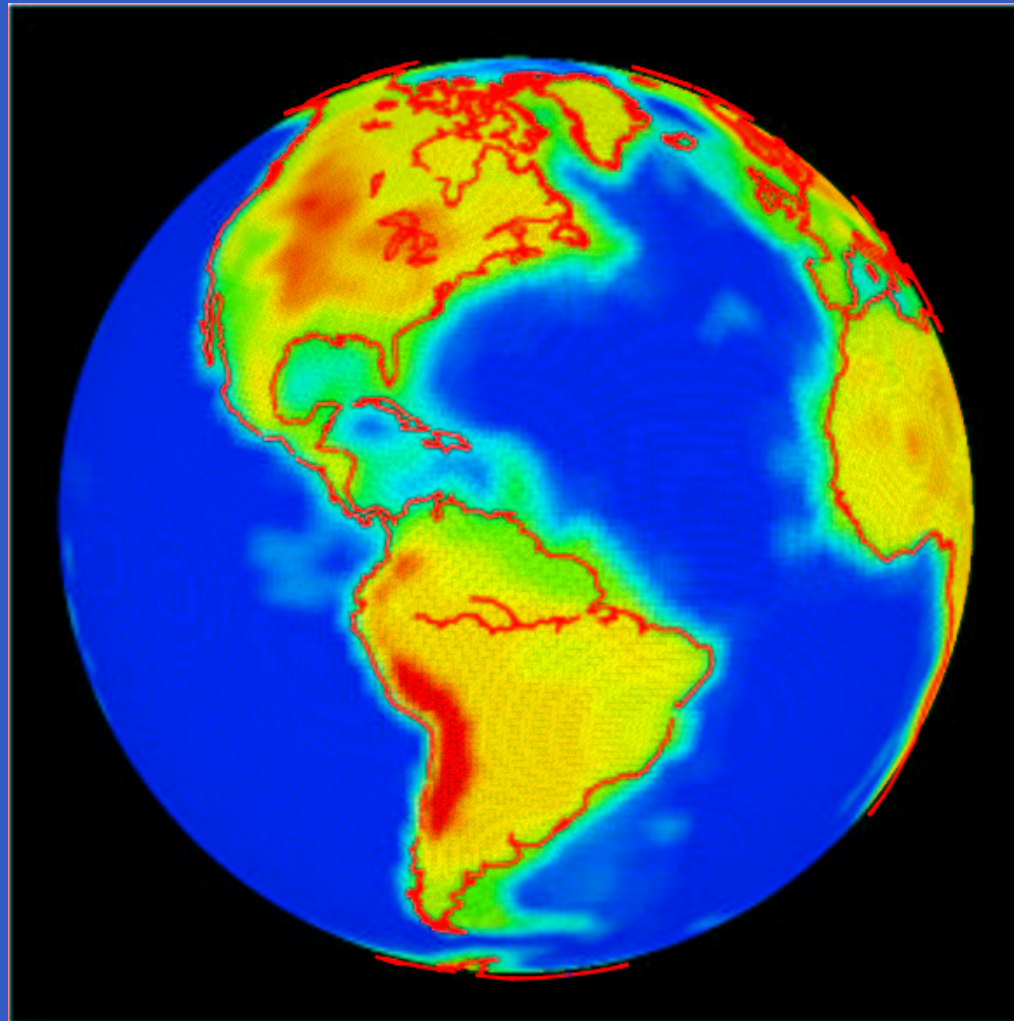
Zinc

Mantle Model



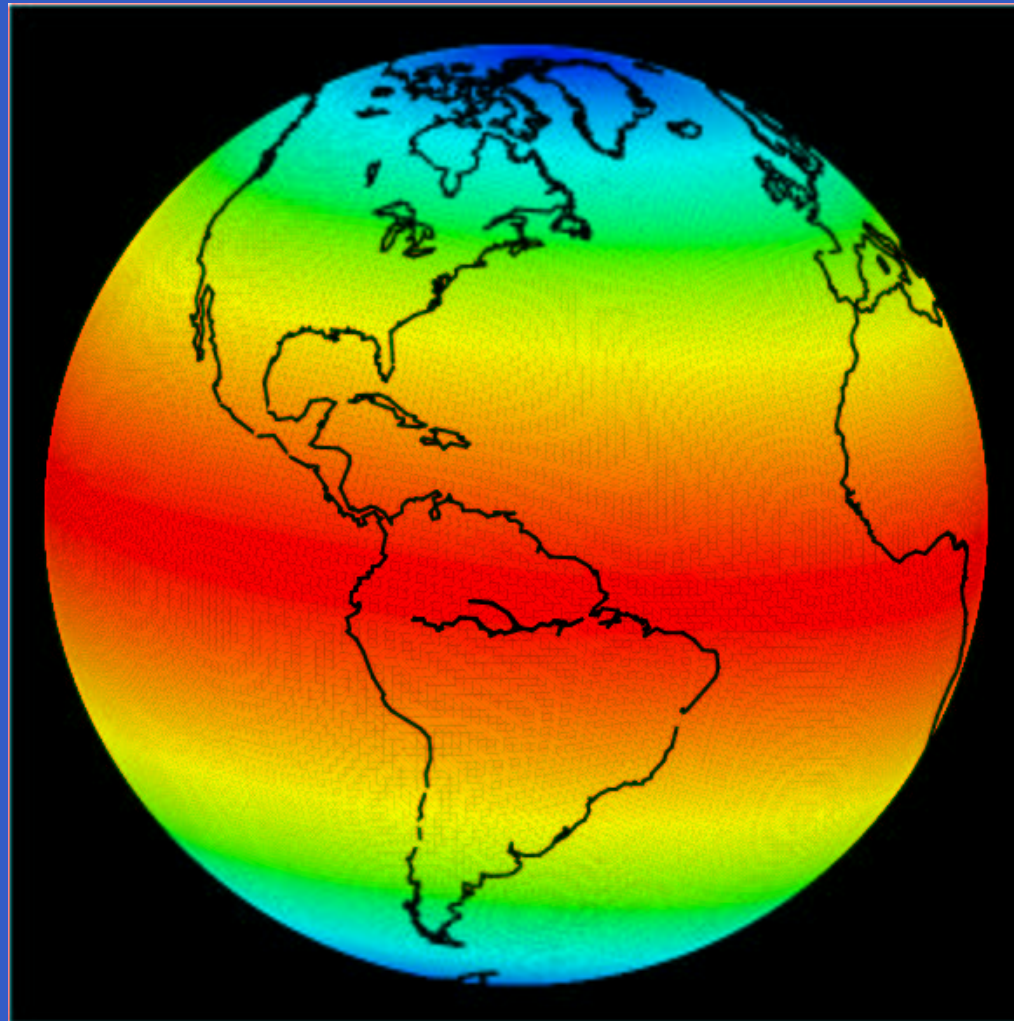
Ritsema *et al.* (1999)

Crustal Model

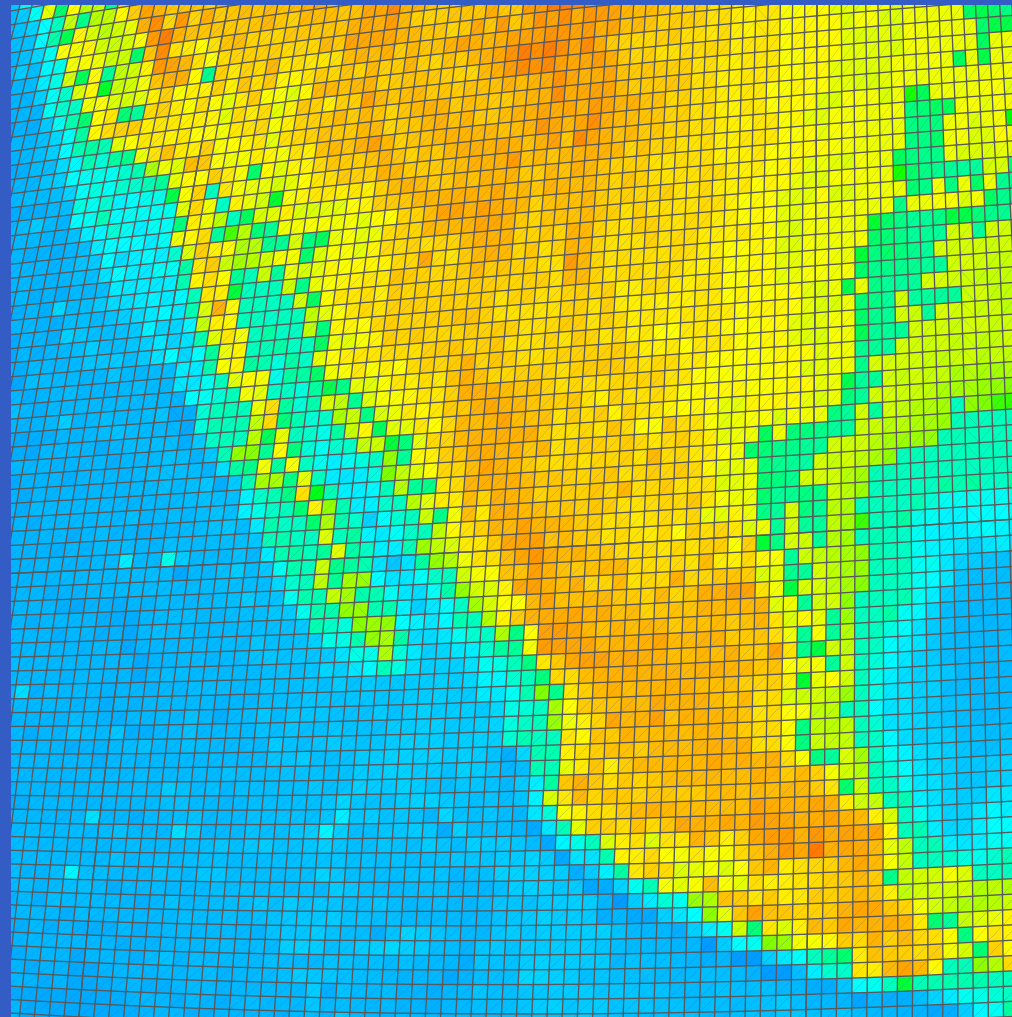


Bassin *et al.* (2000)

Ellipticity

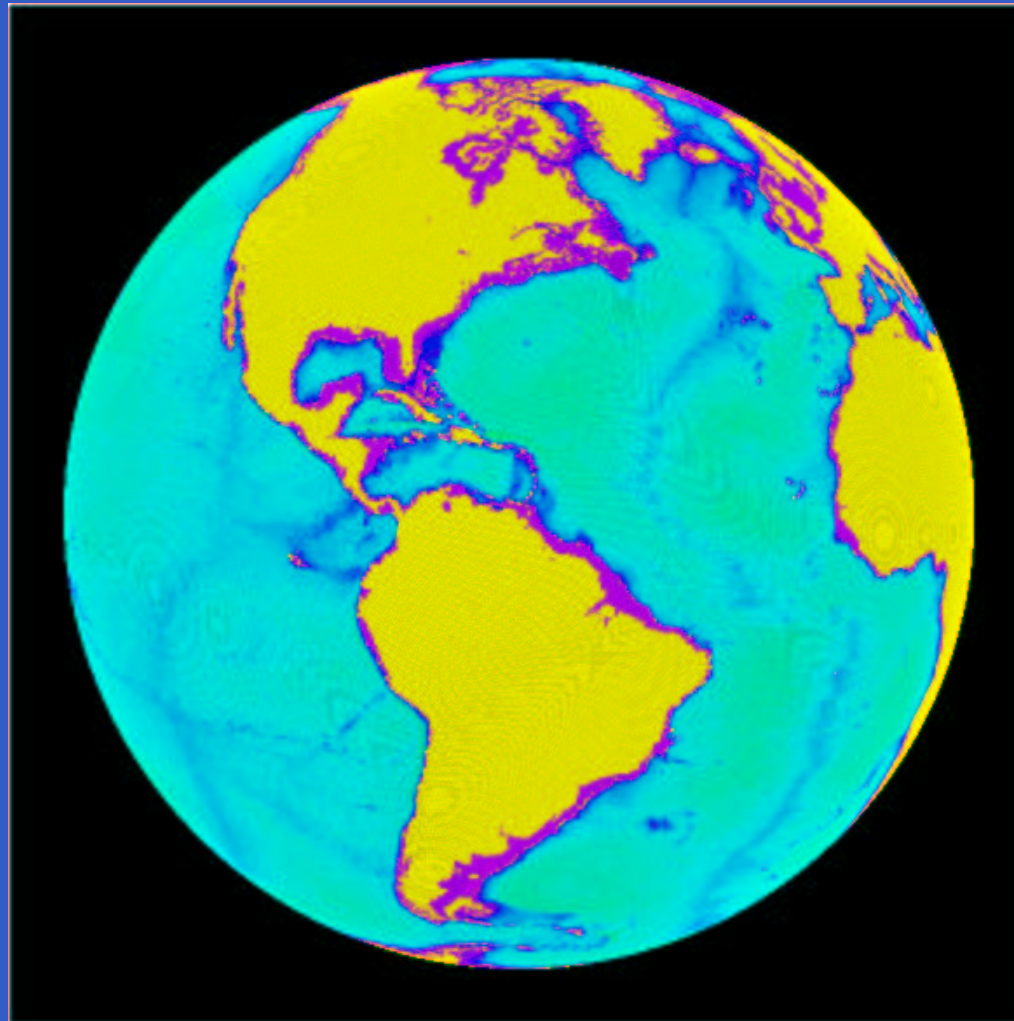


Topography & Bathymetry

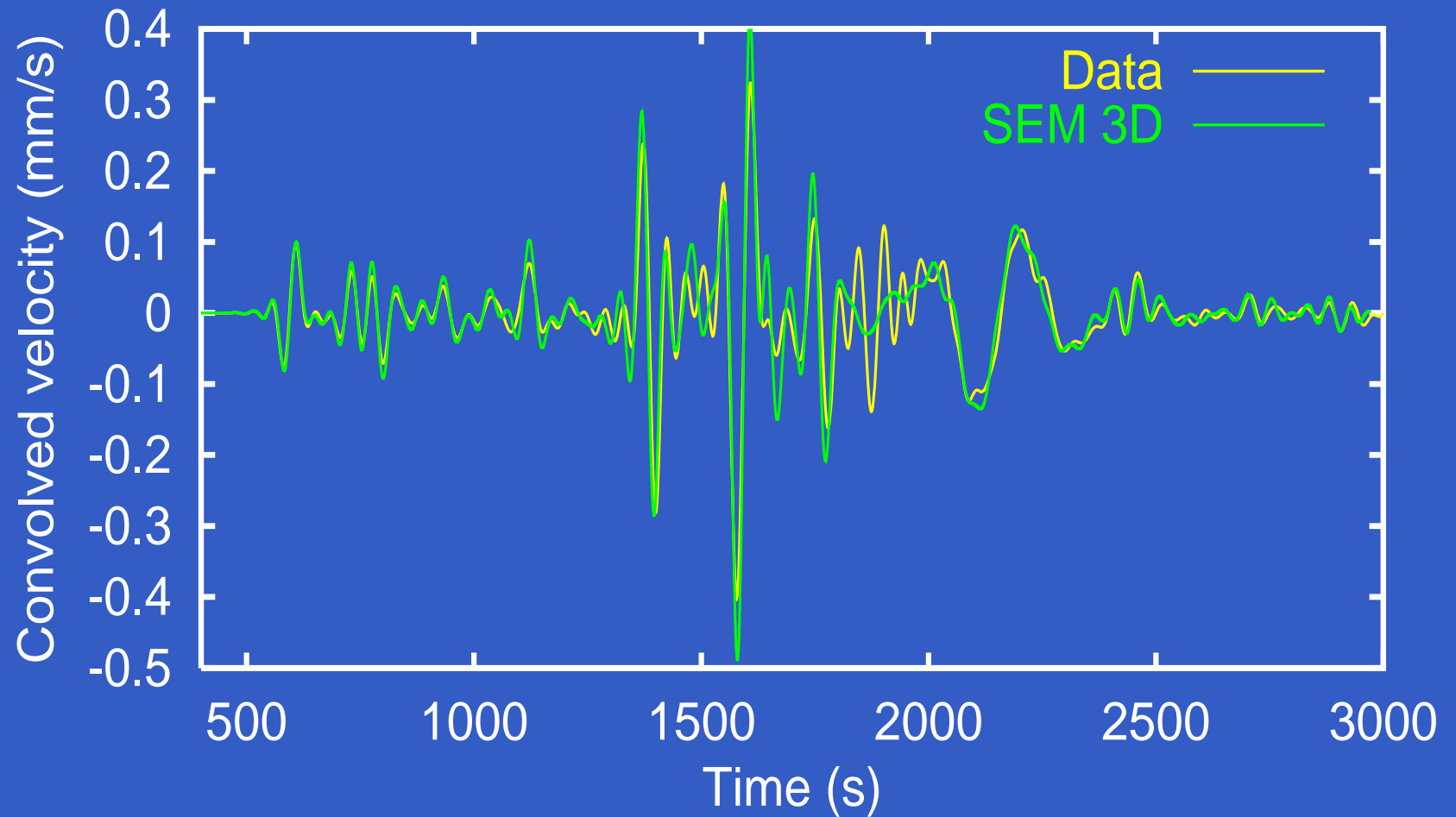


NOAA (1988)

Oceans

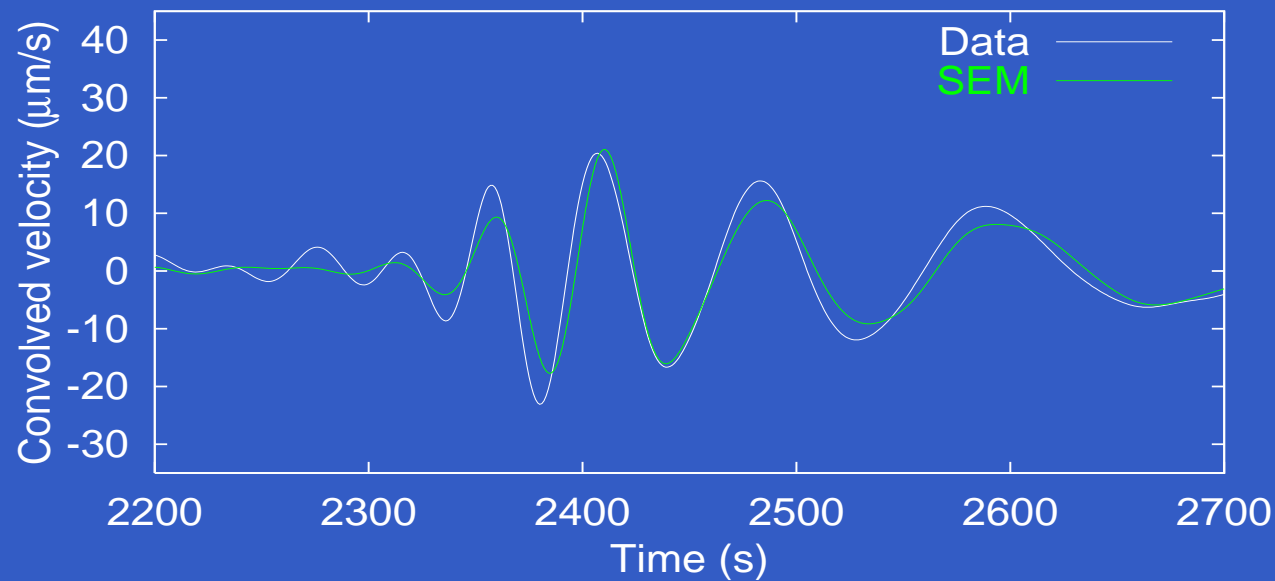
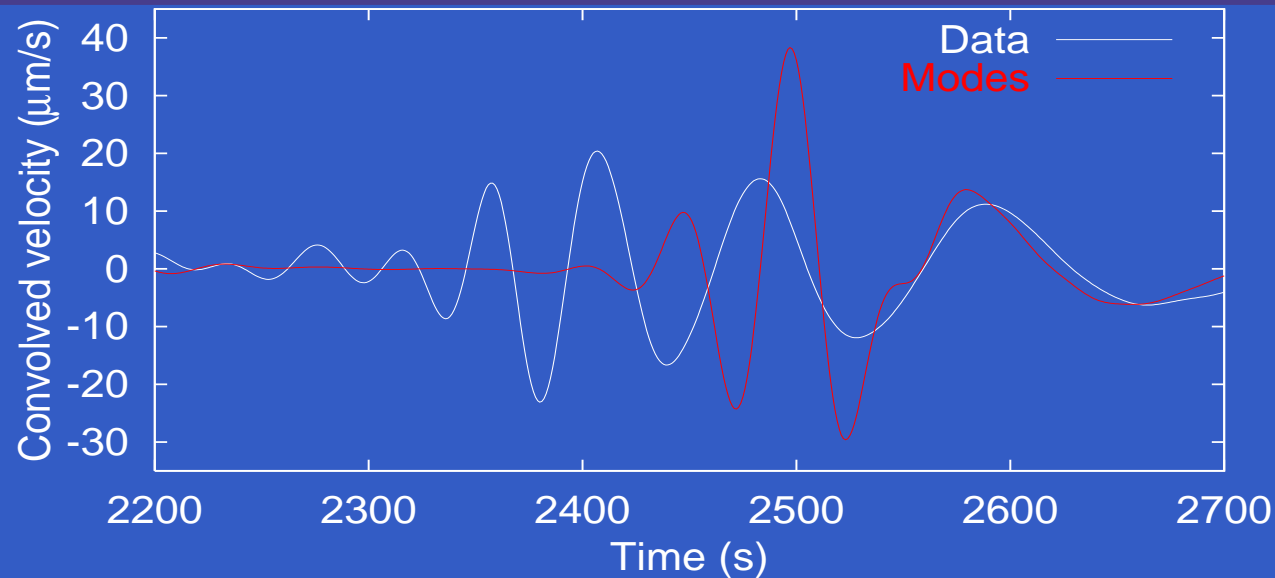


Pasadena (LHZ)



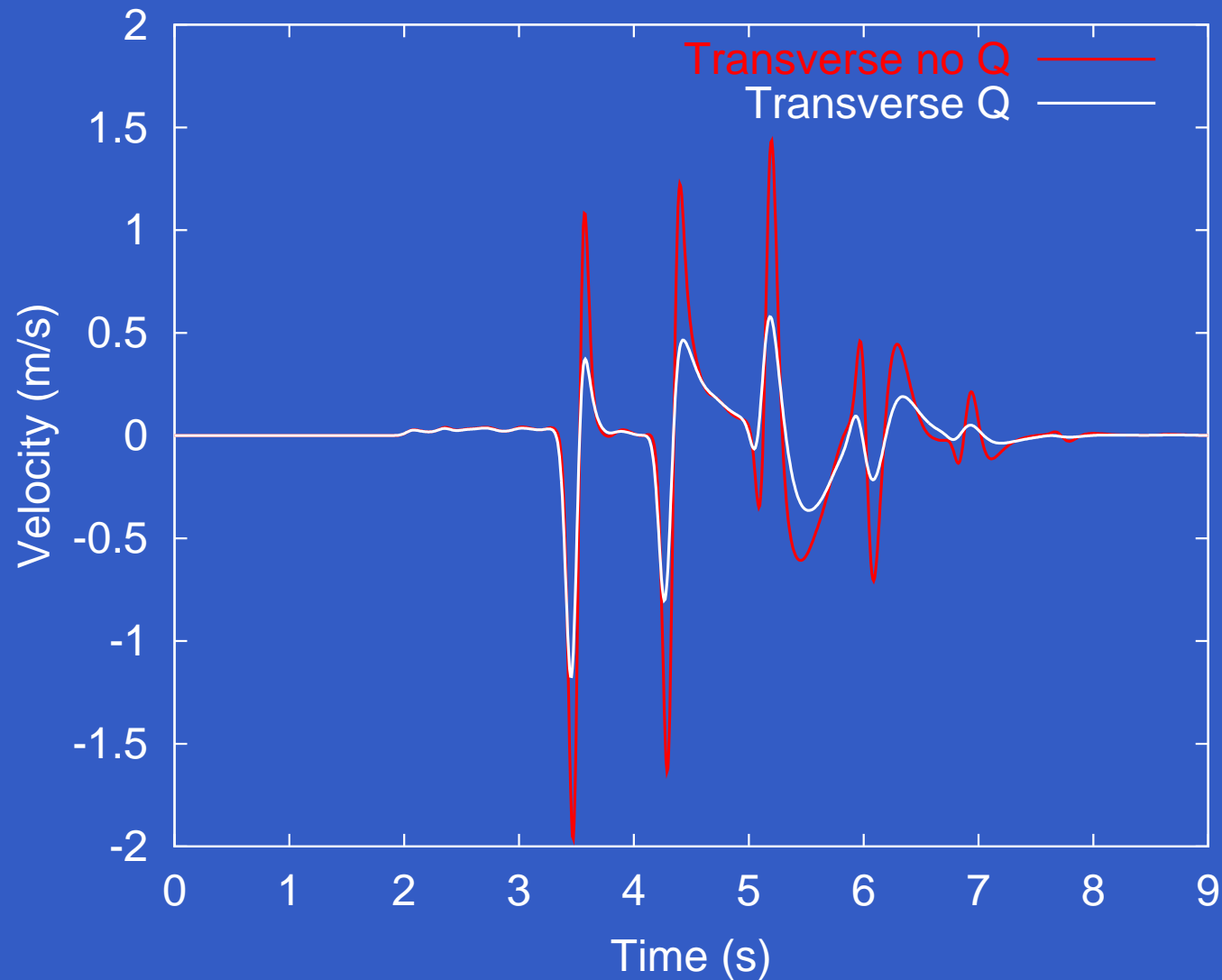
Komatitsch & Tromp (GJI, *in press*, 2002)

Pasadena (LHZ)



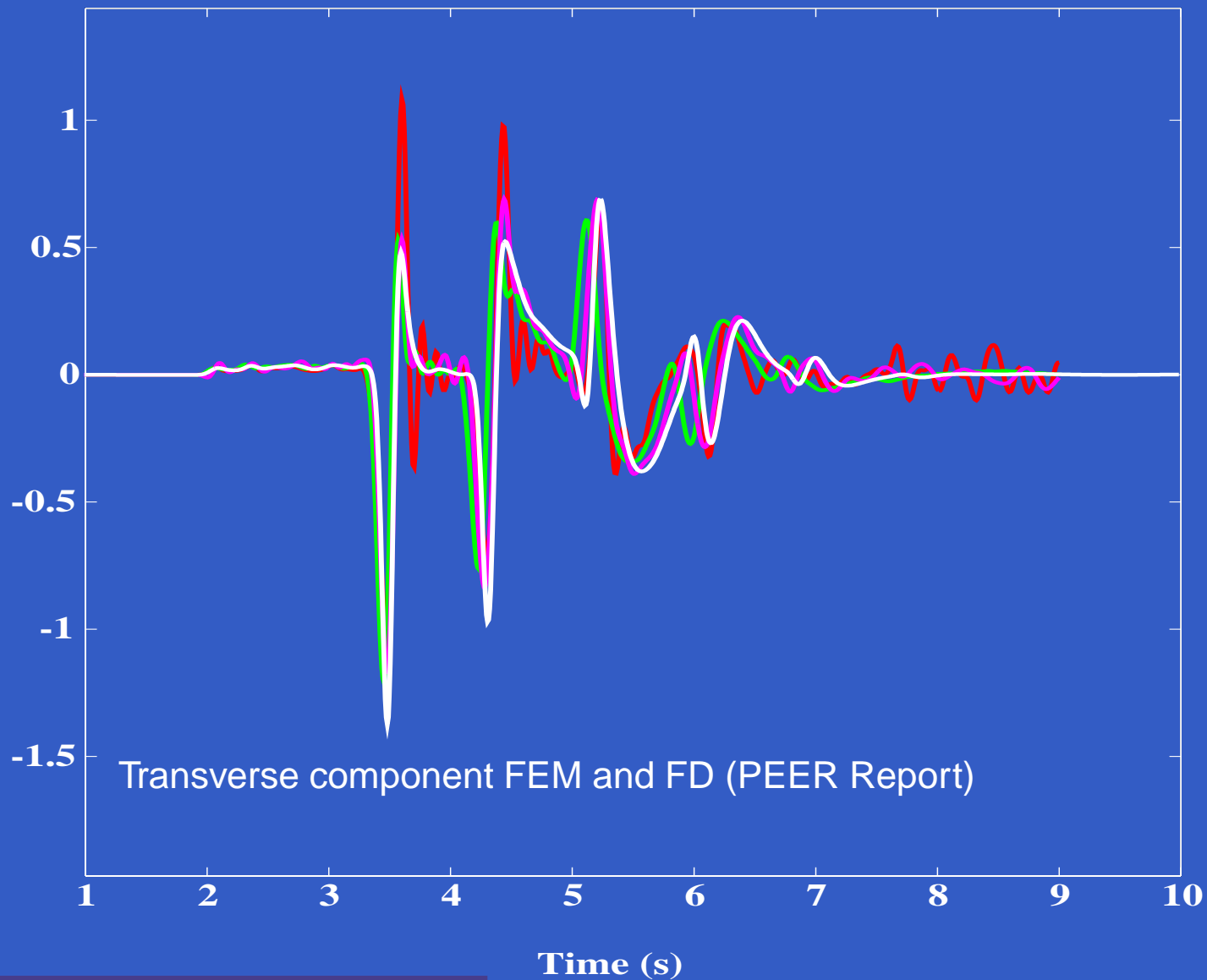
Regional Seismology

SCEC Benchmark LOH.3

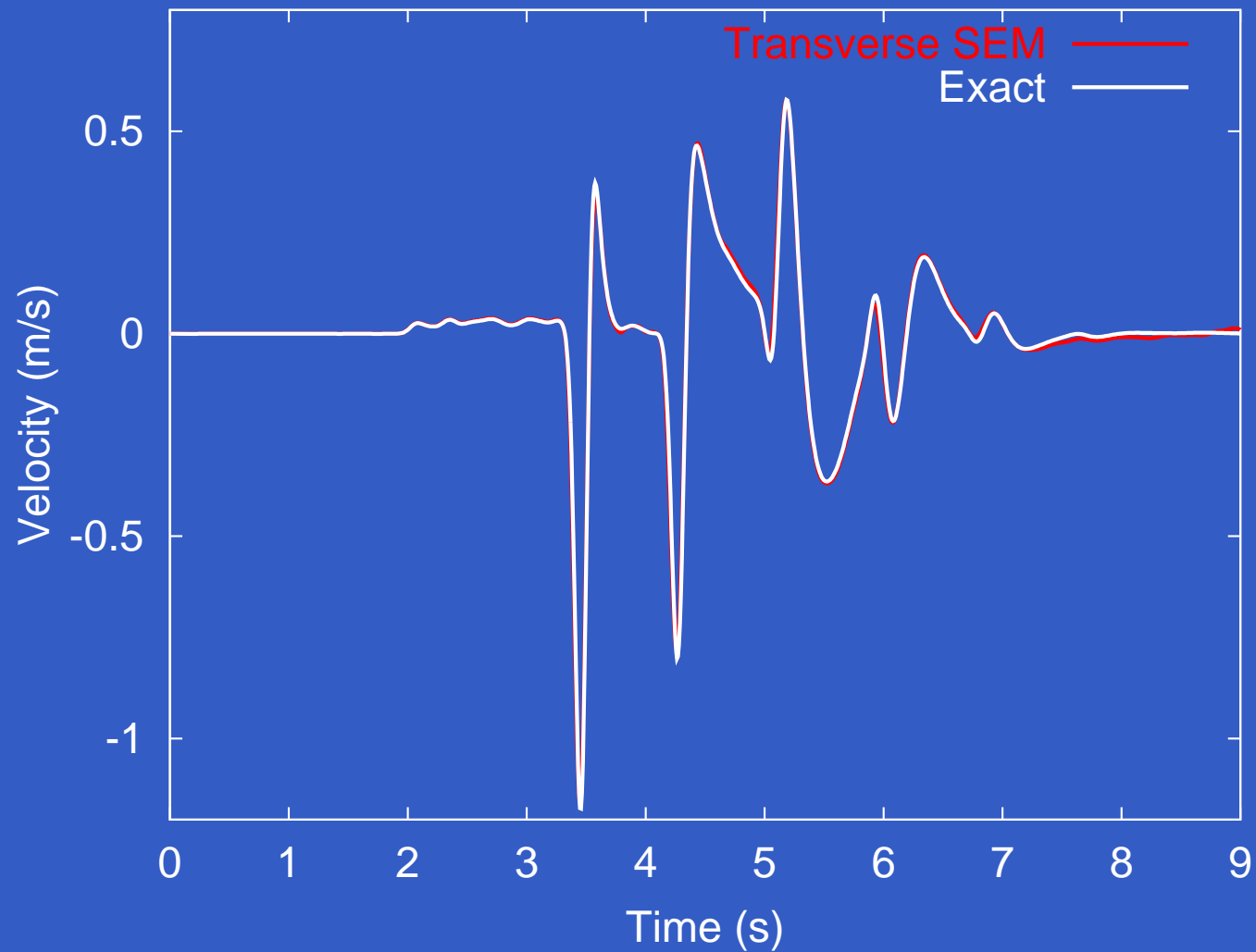


(Courtesy Steve Day)

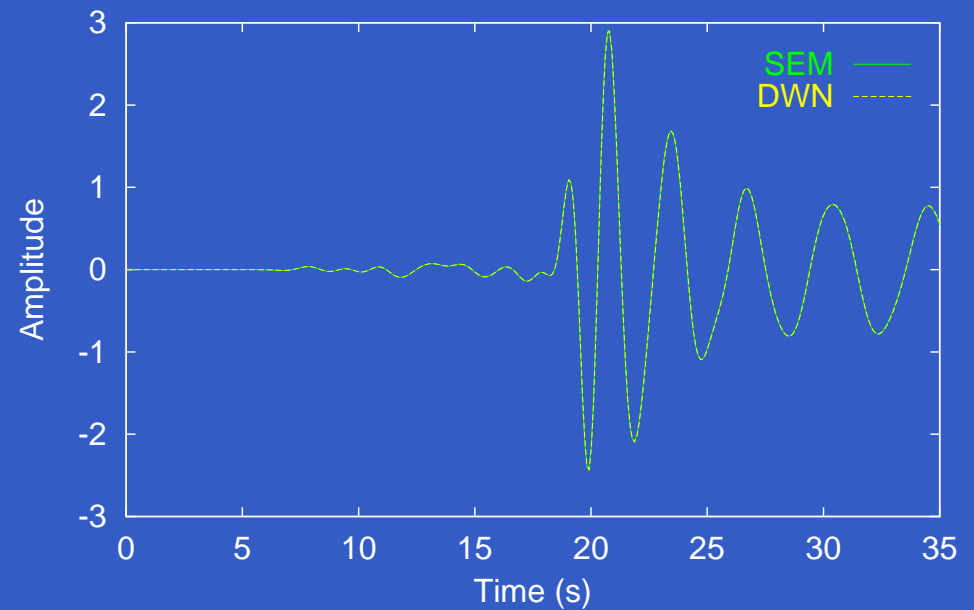
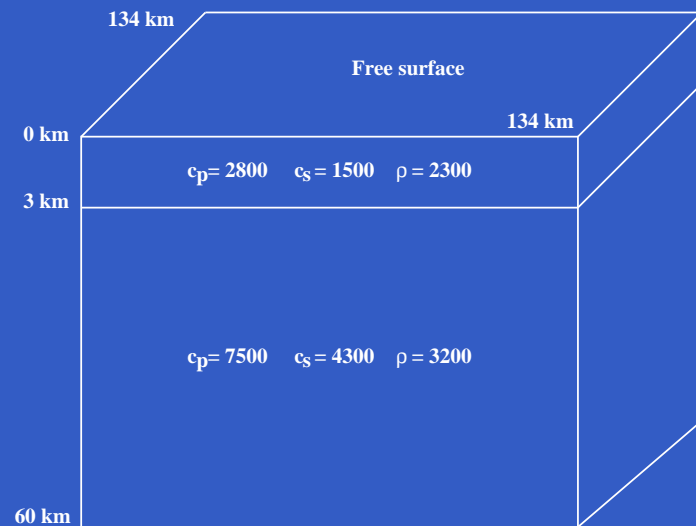
SCEC Benchmark LOH.3



SCEC Benchmark LOH.3

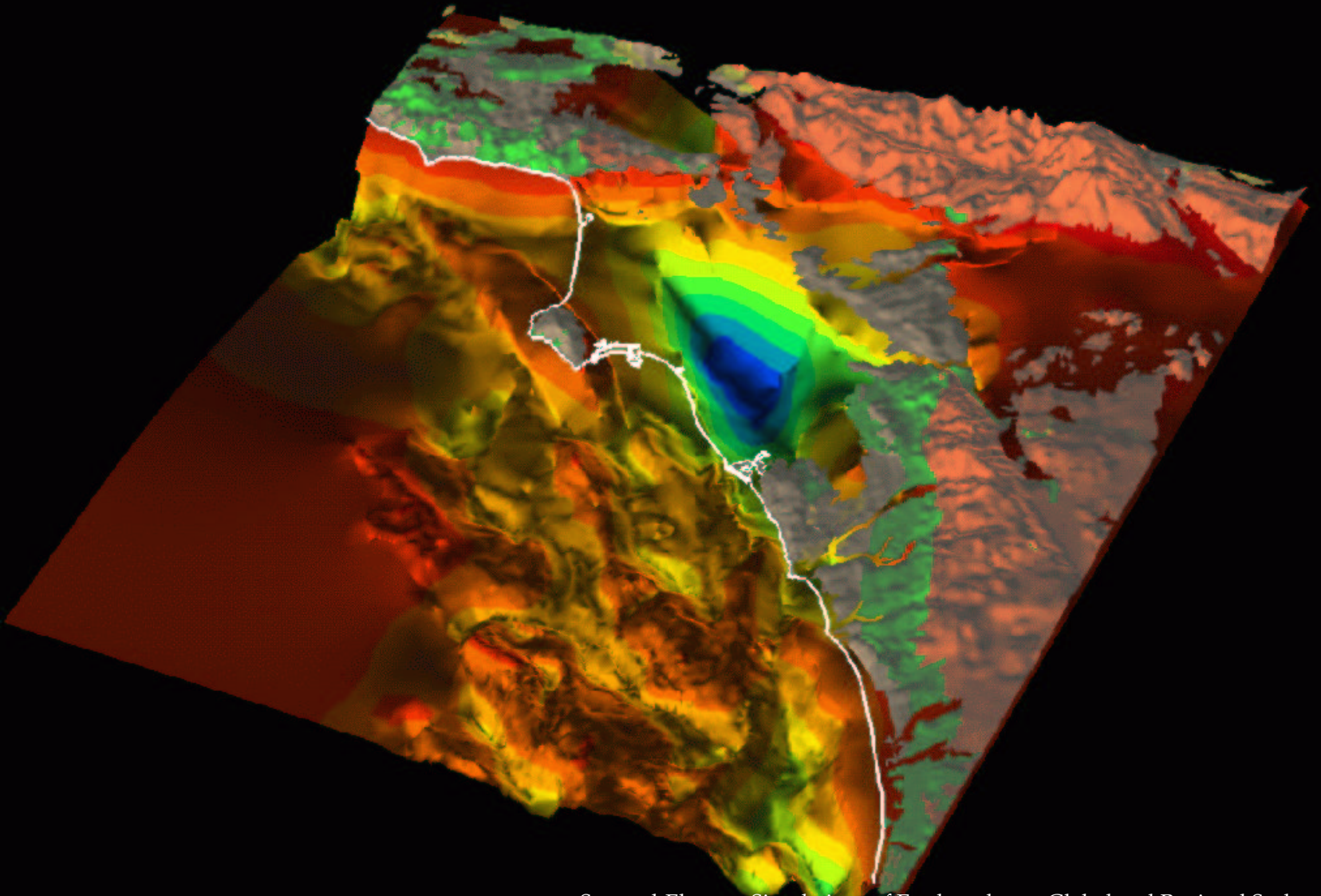


More Benchmarks

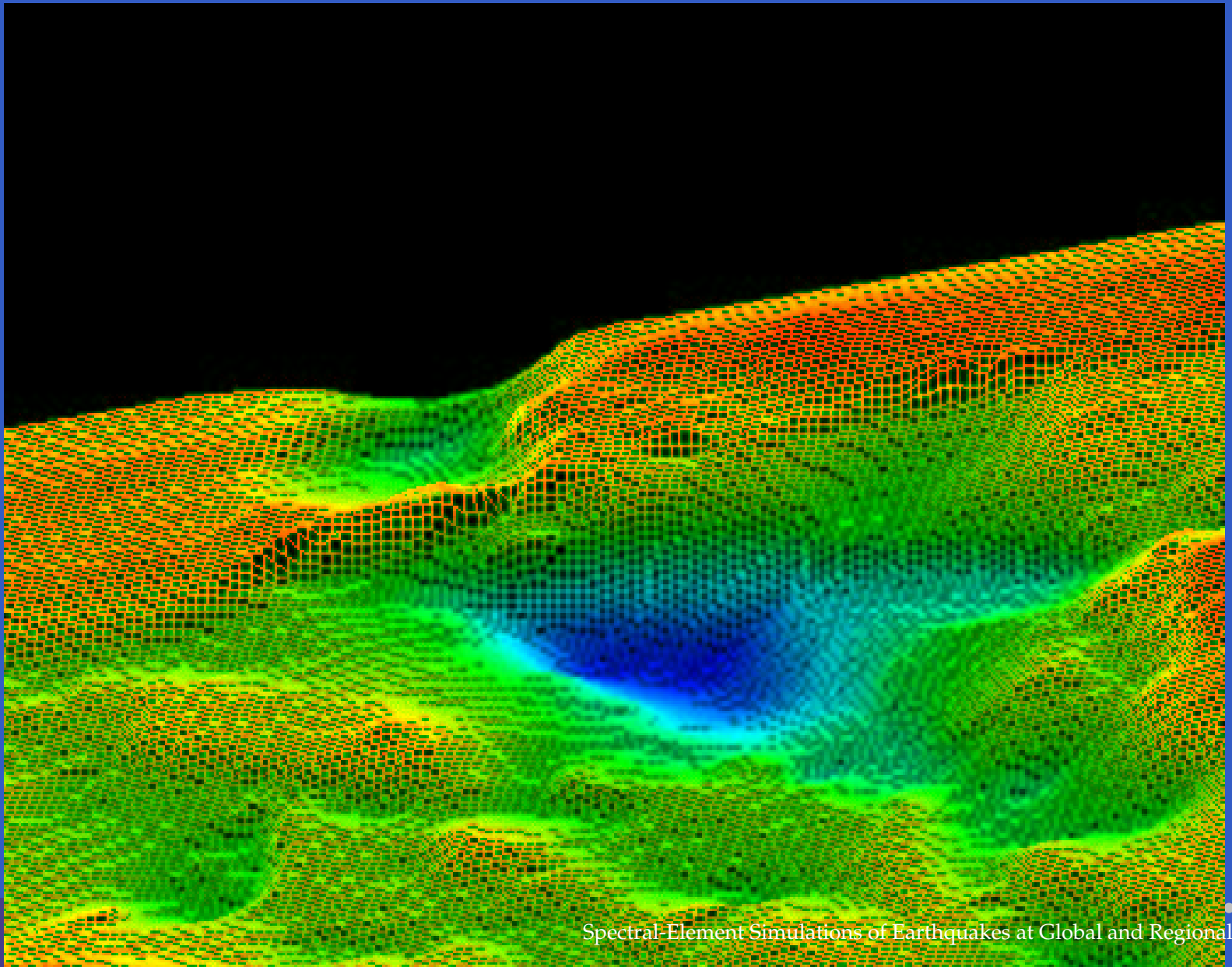


Komatitsch & Tromp (GJI, 139, 806-822, 1999)

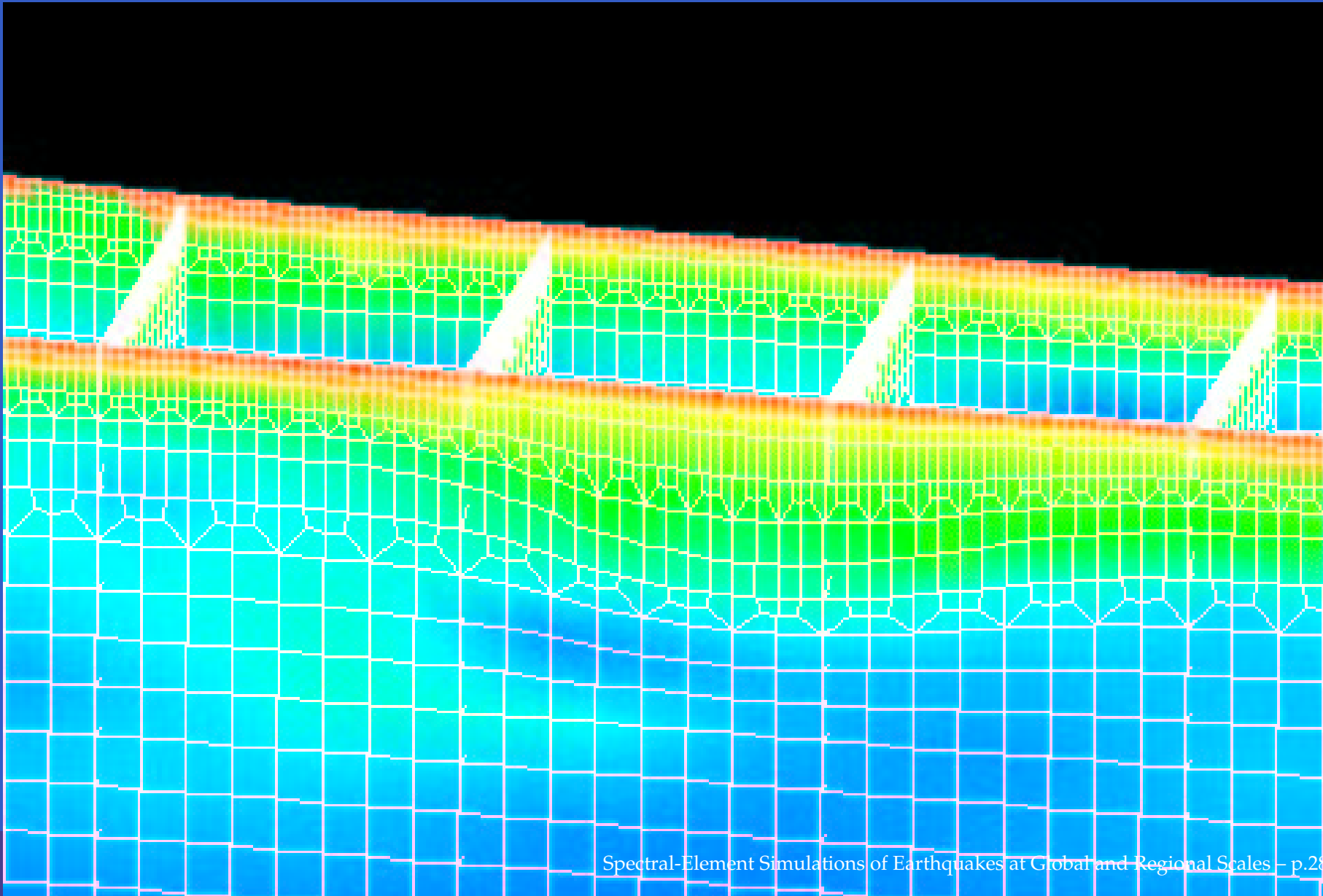
Harvard LA Basin Model



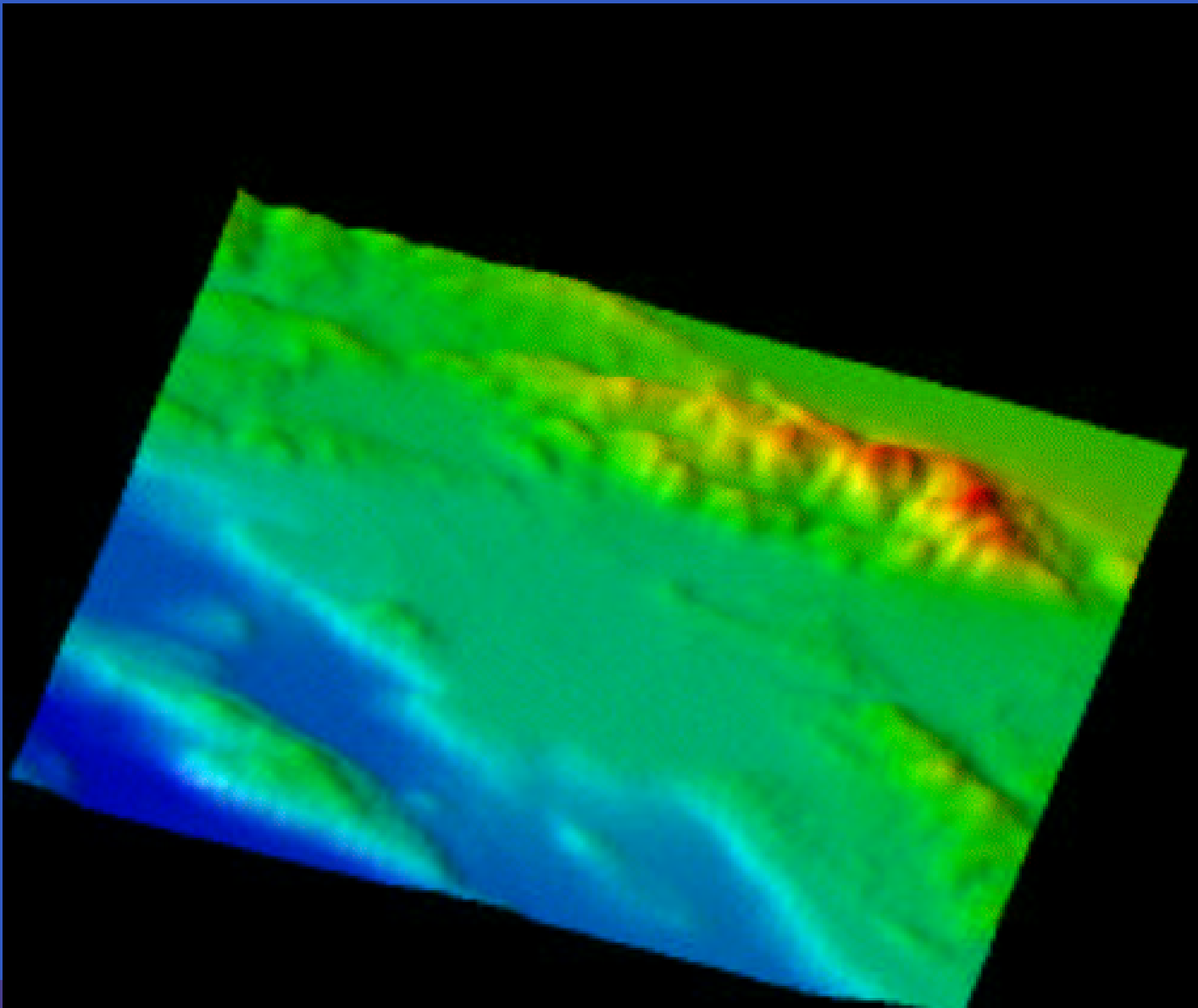
Basement Surface (From South)



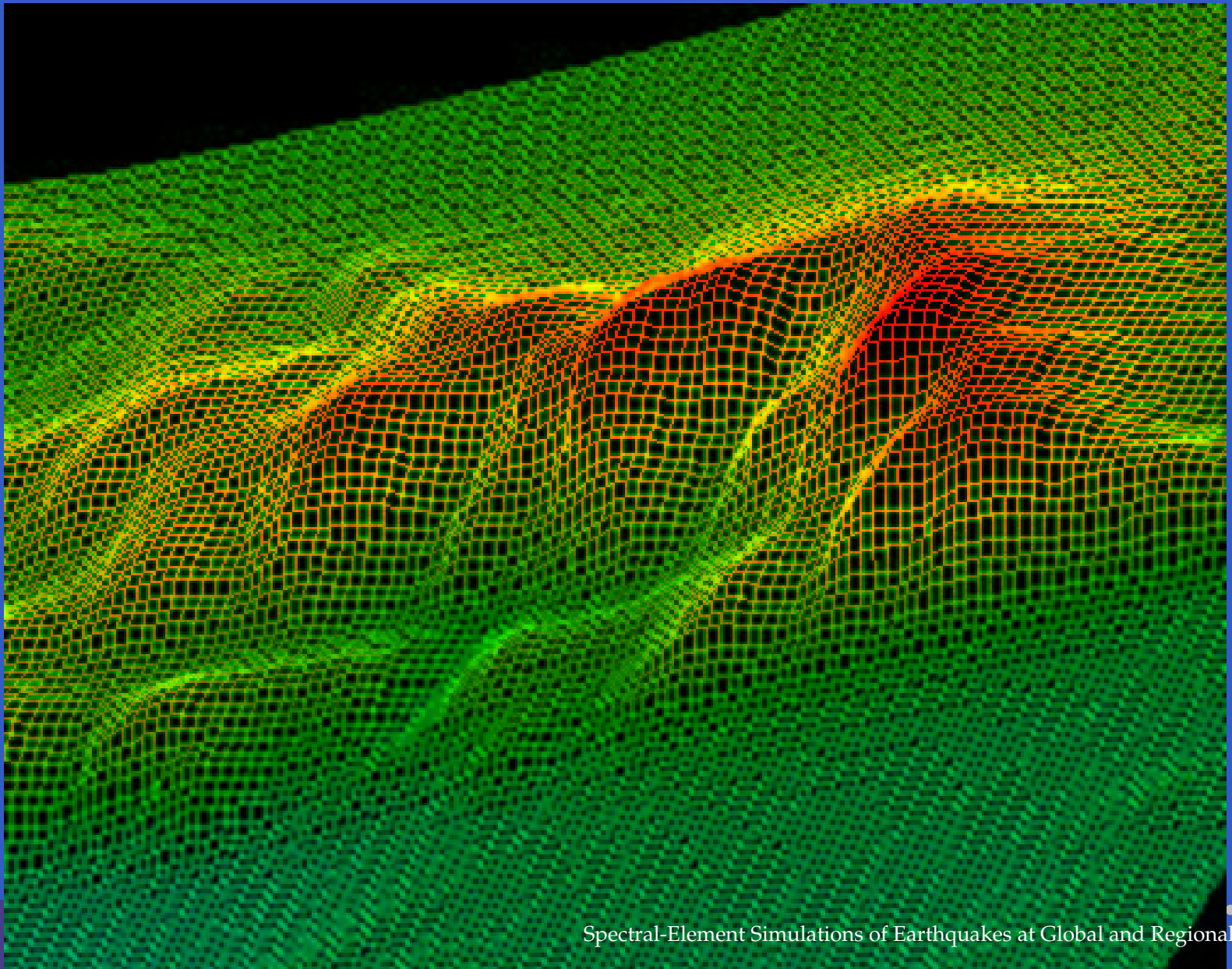
LA Basin Mesh (East-West)



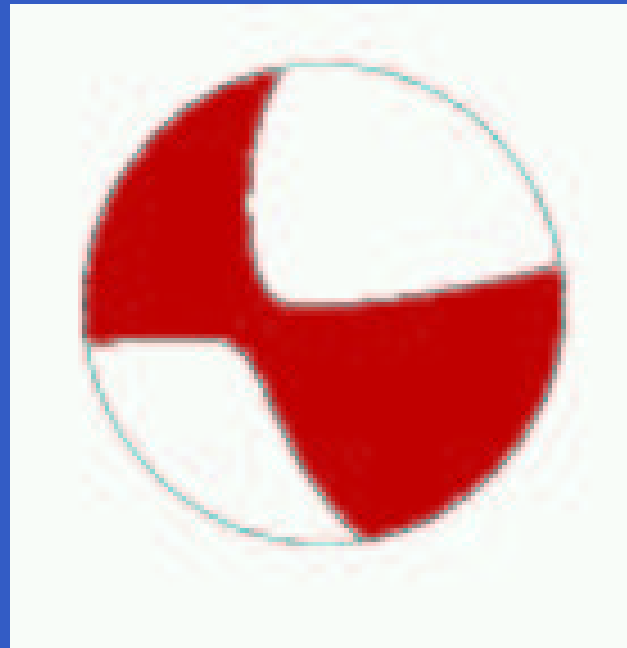
Topography



San Gabriel Mesh



October 9, 2001, Hollywood



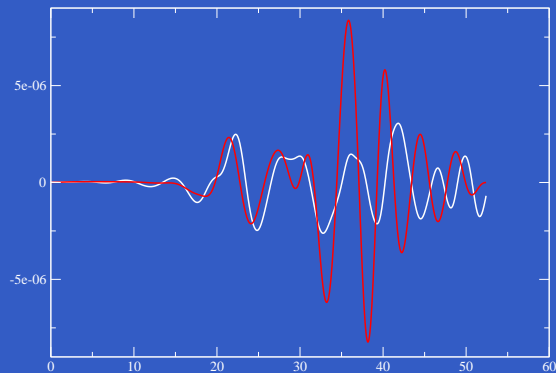
Depth: 5 km, $M = 4.0$

Polet (2002)

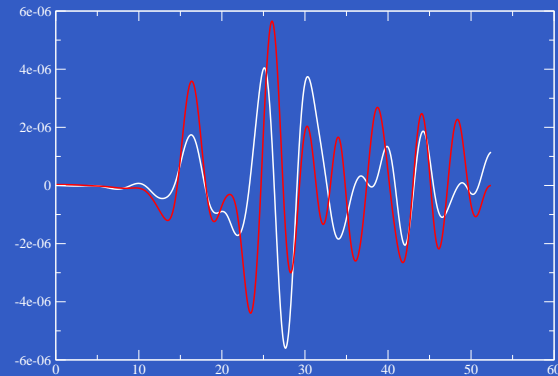
October 9, 2001, Hollywood



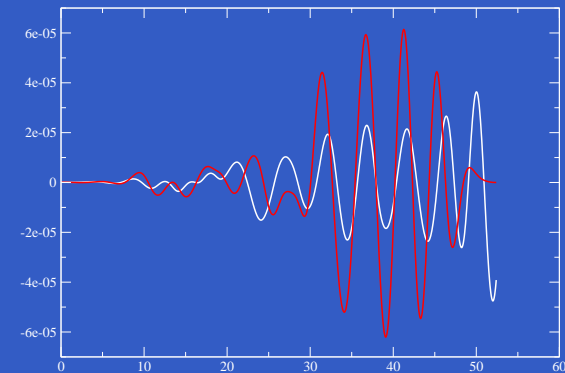
ADO (59° , 101 km)



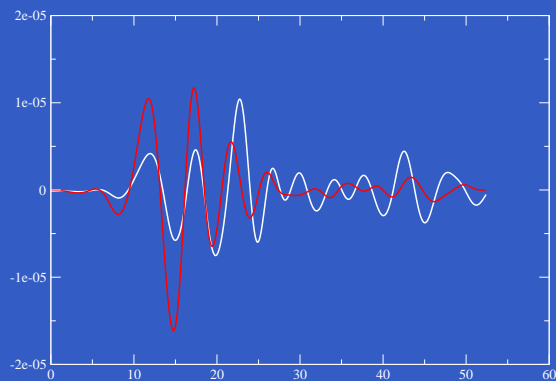
BFS (75° , 69 km)



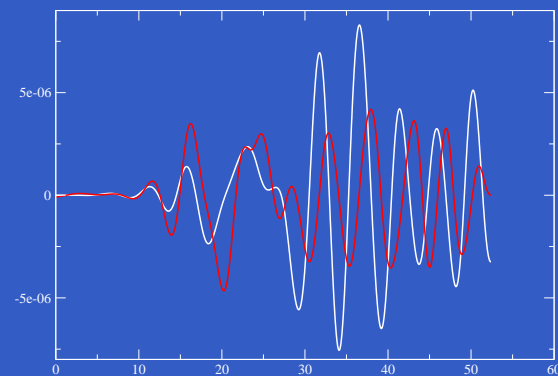
BRE (129° , 47 km)



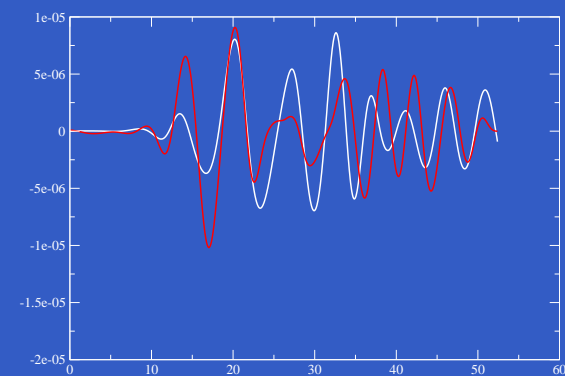
CHF (49° , 43 km)



CHN (97° , 65 km)



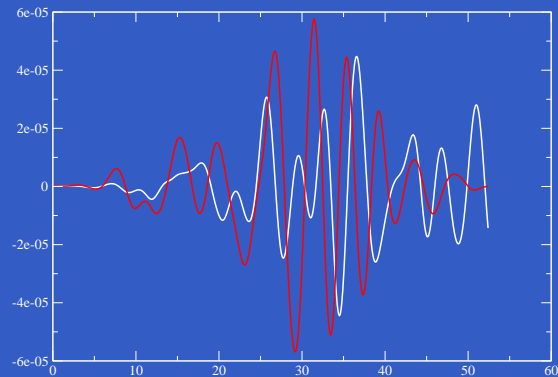
CPP (92° , 53 km)



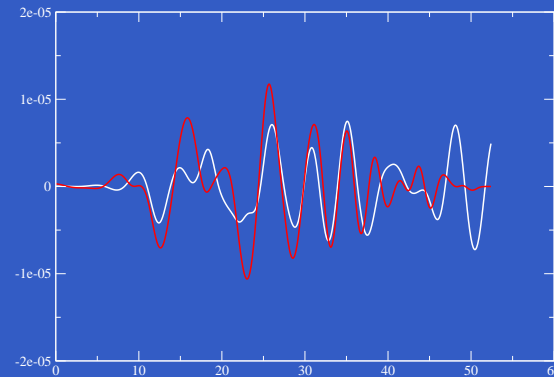
October 9, 2001, Hollywood



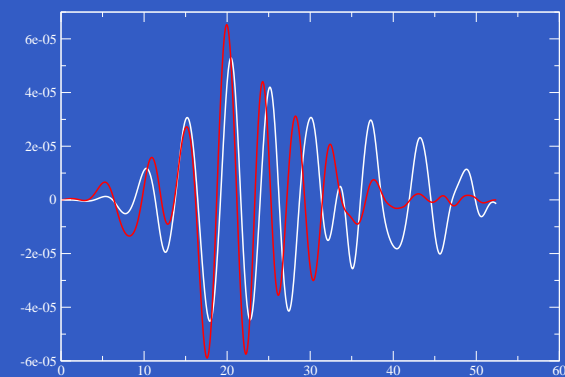
DLA (134°, 36 km)



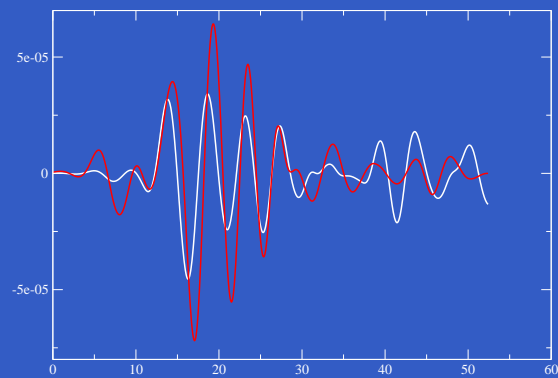
FMP (169°, 41 km)



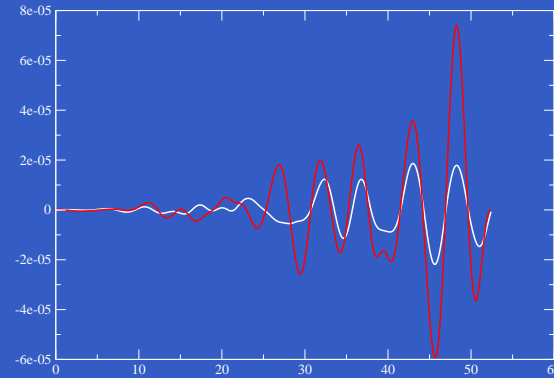
LAF (169°, 23 km)



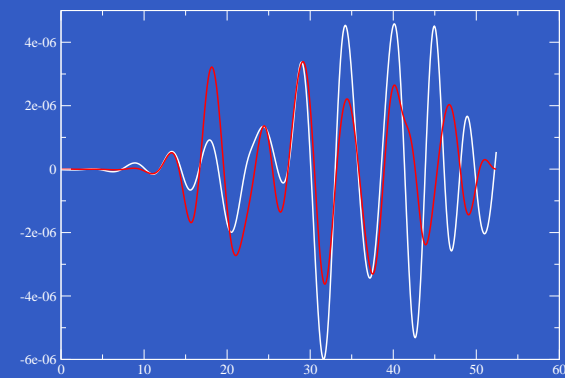
LGB (117°, 24 km)



LLS (137°, 59 km)



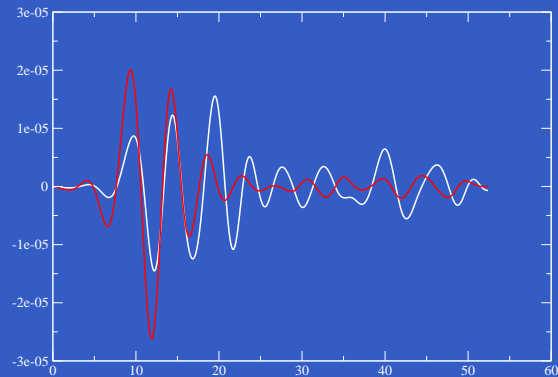
MLS (96°, 76 km)



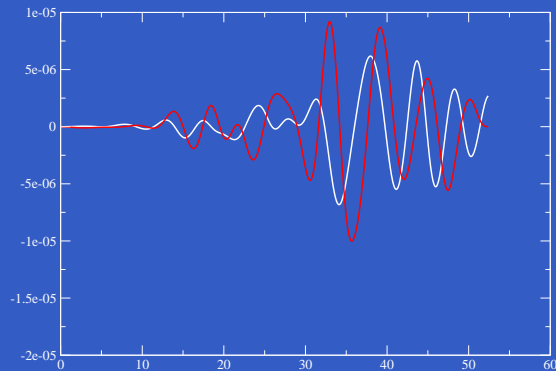
October 9, 2001, Hollywood



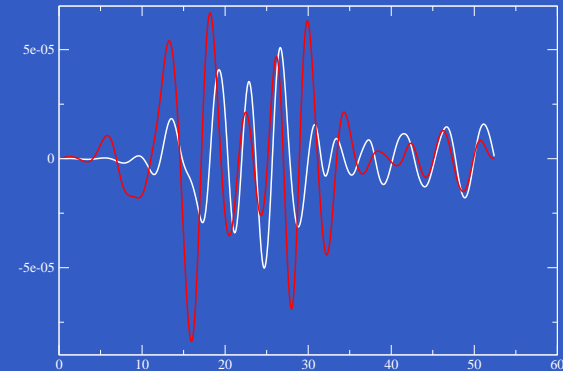
MWC (61° , 34 km)



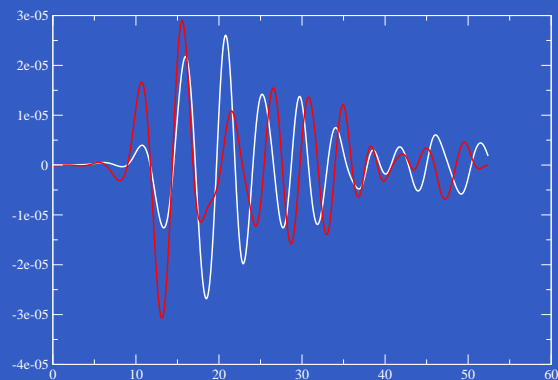
PLS (113° , 78 km)



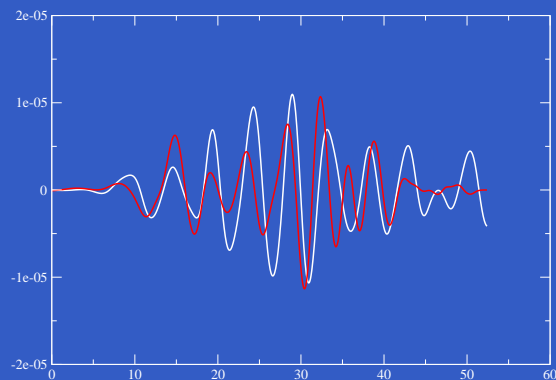
RIN (338° , 25 km)



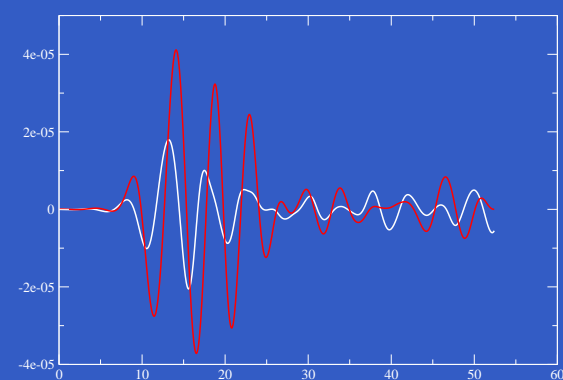
RIO (85° , 37 km)



RPV (183° , 37 km)



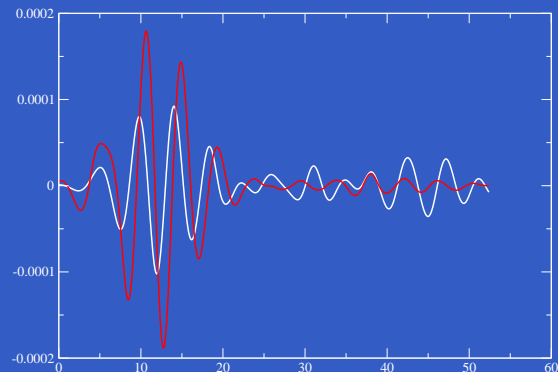
RUS (96° , 28 km)



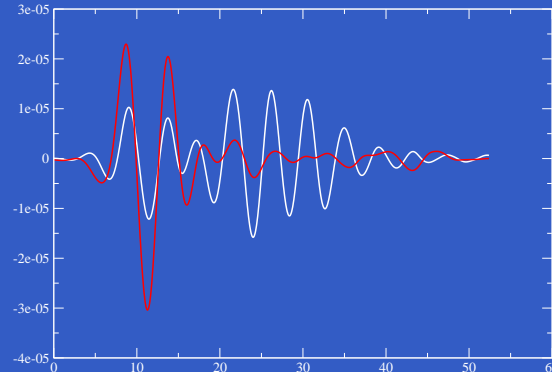
October 9, 2001, Hollywood



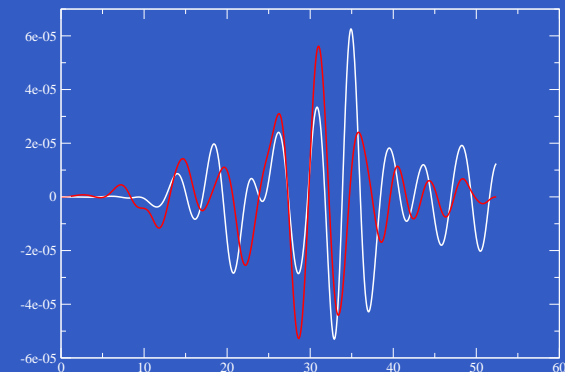
SMS (227°, 10 km)



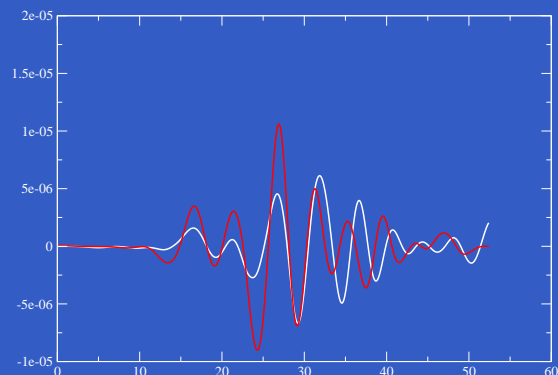
SPF (266°, 25 km)



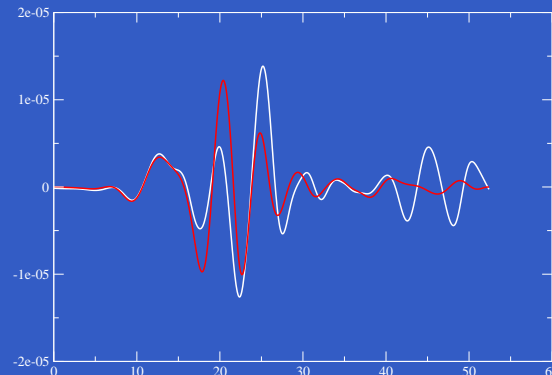
STS (187°, 35 km)



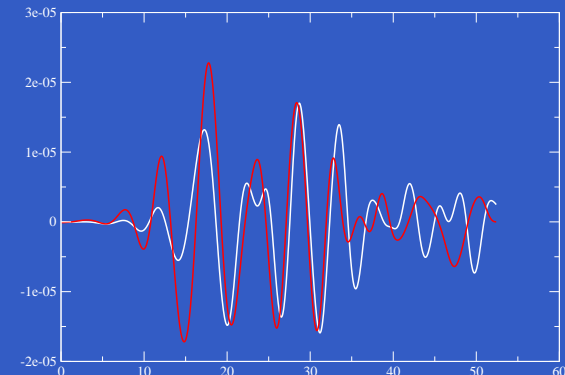
TA2 (62°, 73 km)



VCS (27°, 52 km)



WLT (100°, 40 km)

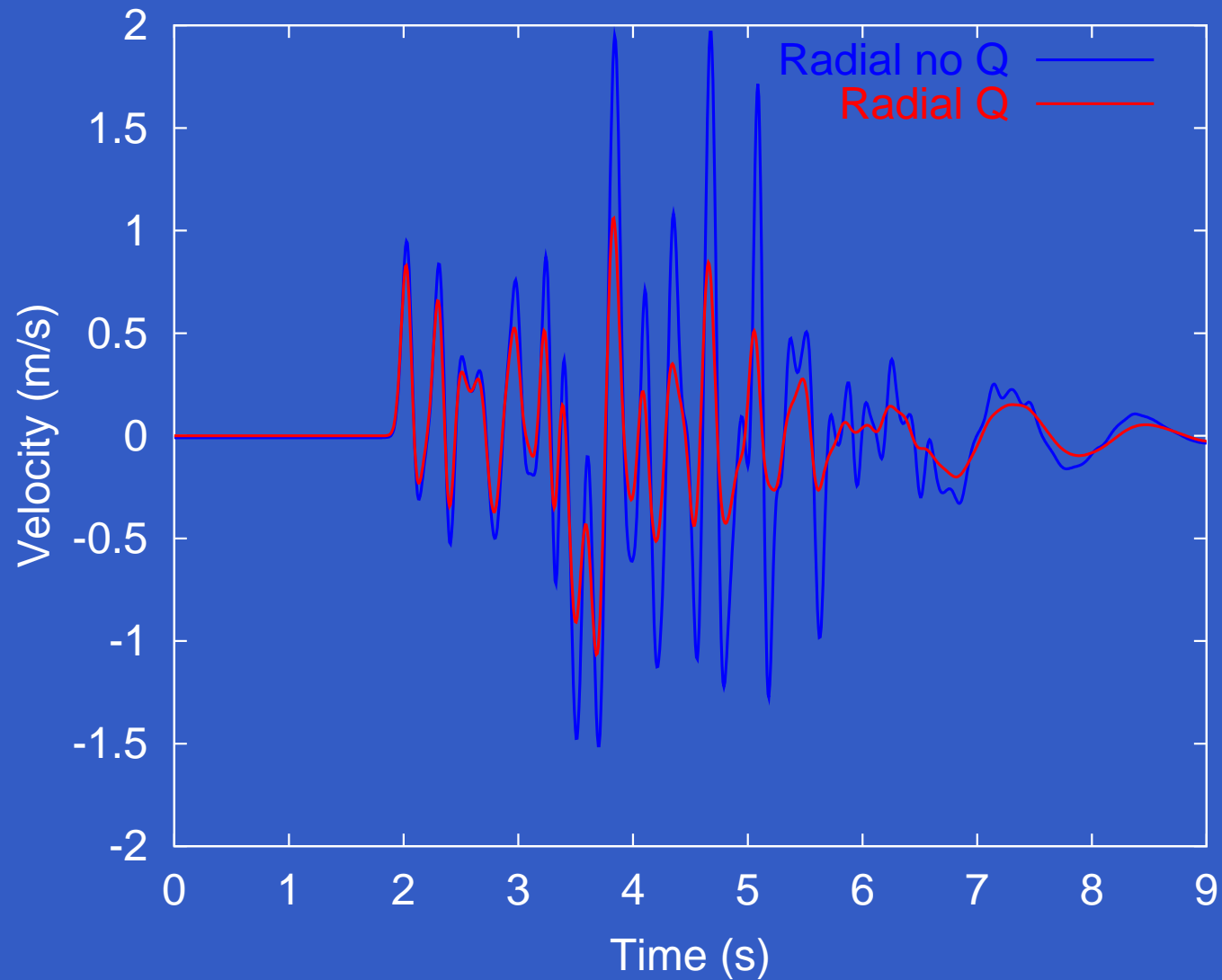


Conclusions



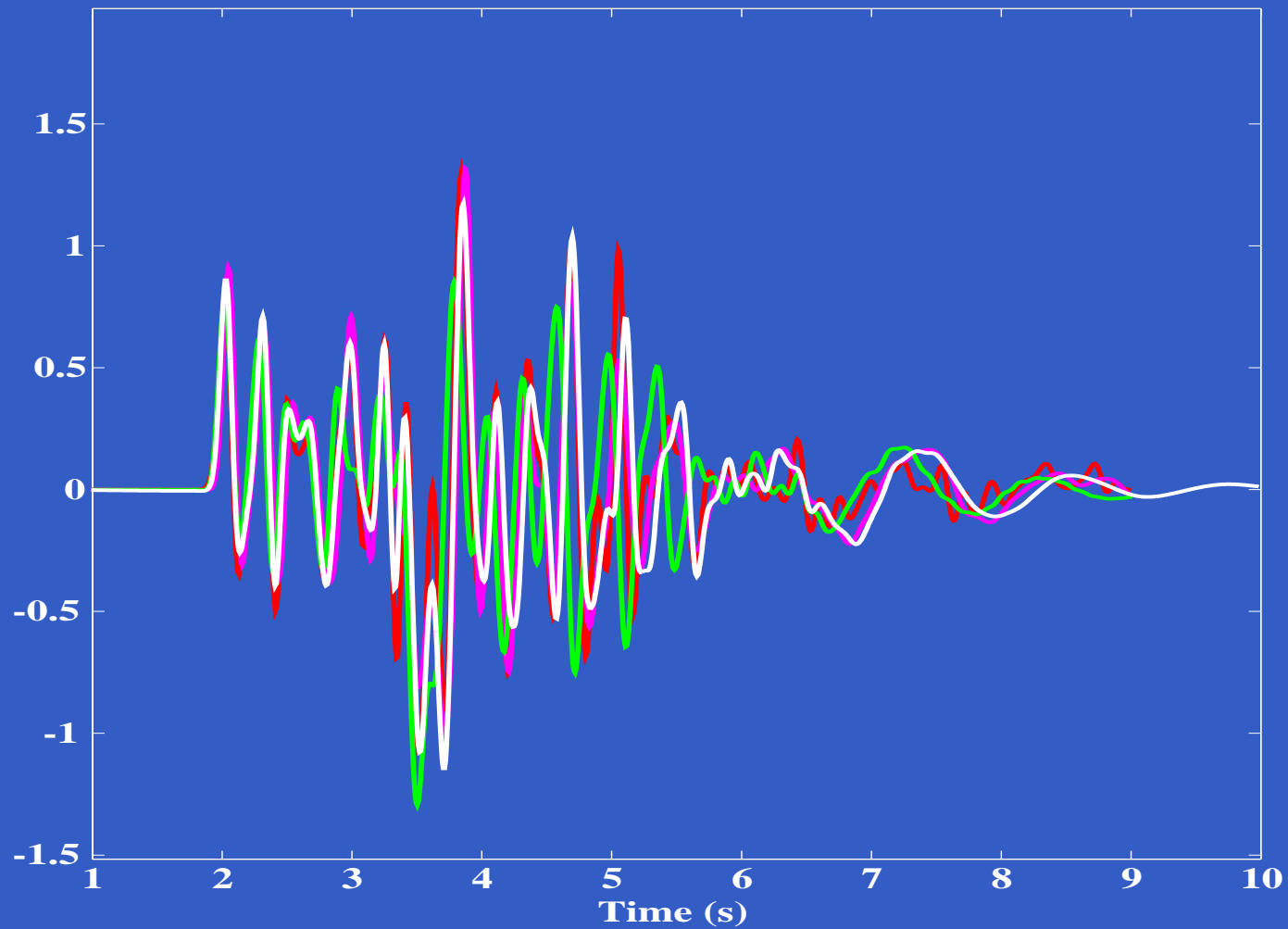
- Spectral-Element Method:
 - minimal grid dispersion & anisotropy
 - free-surface topography
 - first-order discontinuities
 - fluid-solid boundaries
 - attenuation
 - anisotropy
 - mesh coarsening (CPU time & memory)
- SEM accurate in global seismology
- SEM promising in strong-motion seismology

SCEC Benchmark LOH.3



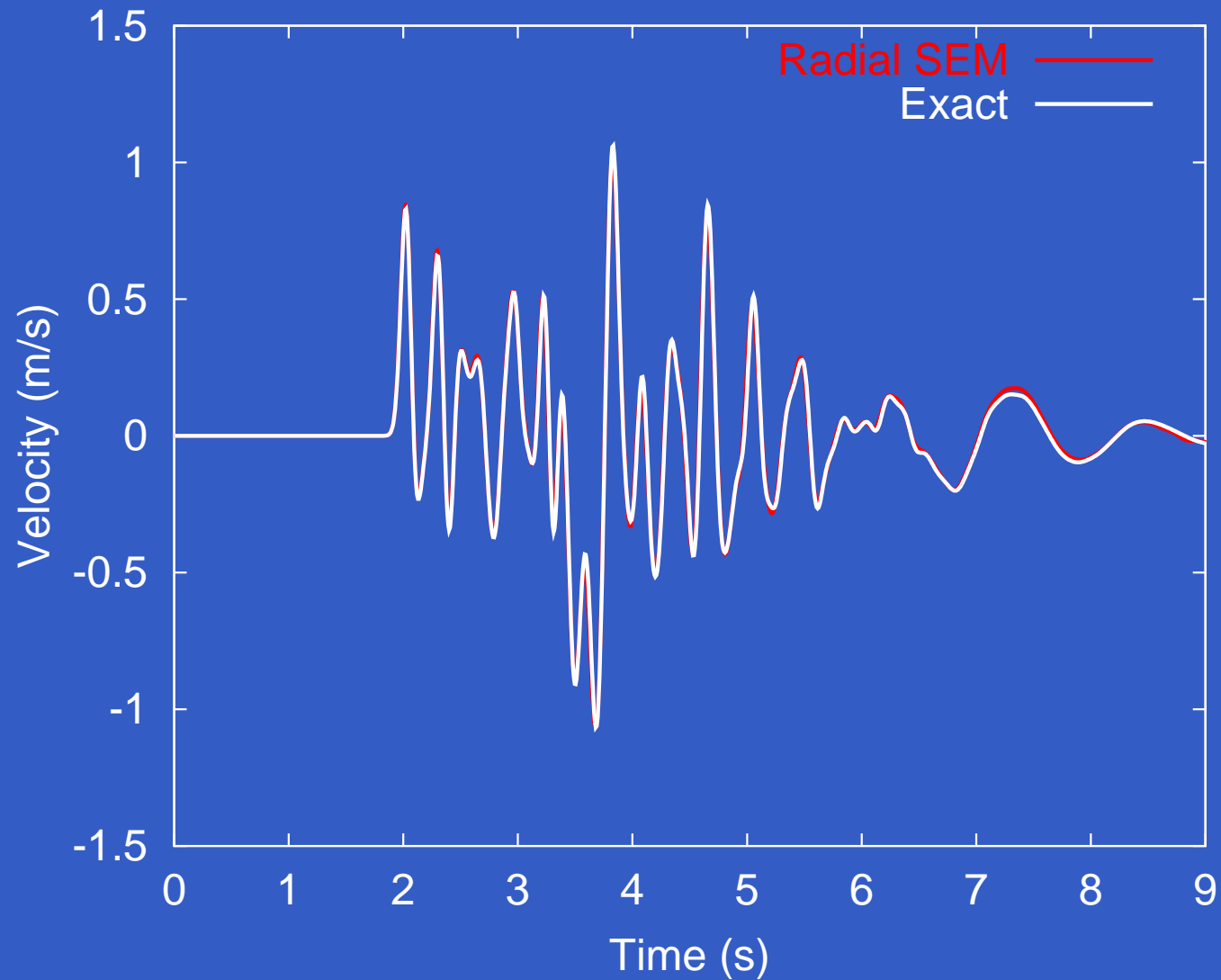
(Courtesy Steve Day)

SCEC Benchmark LOH.3

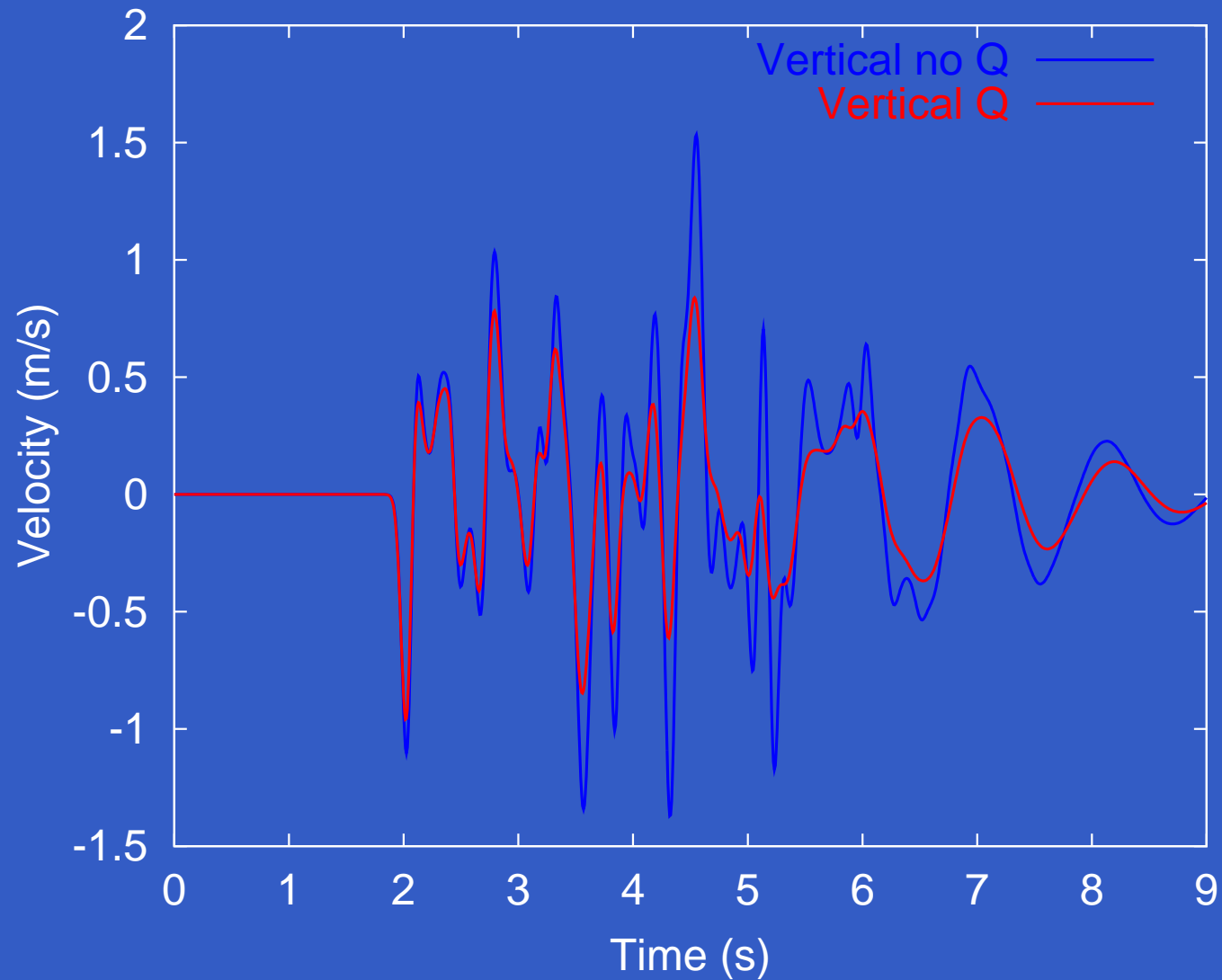


Radial component FEM and FD (PEER Report)

SCEC Benchmark LOH.3

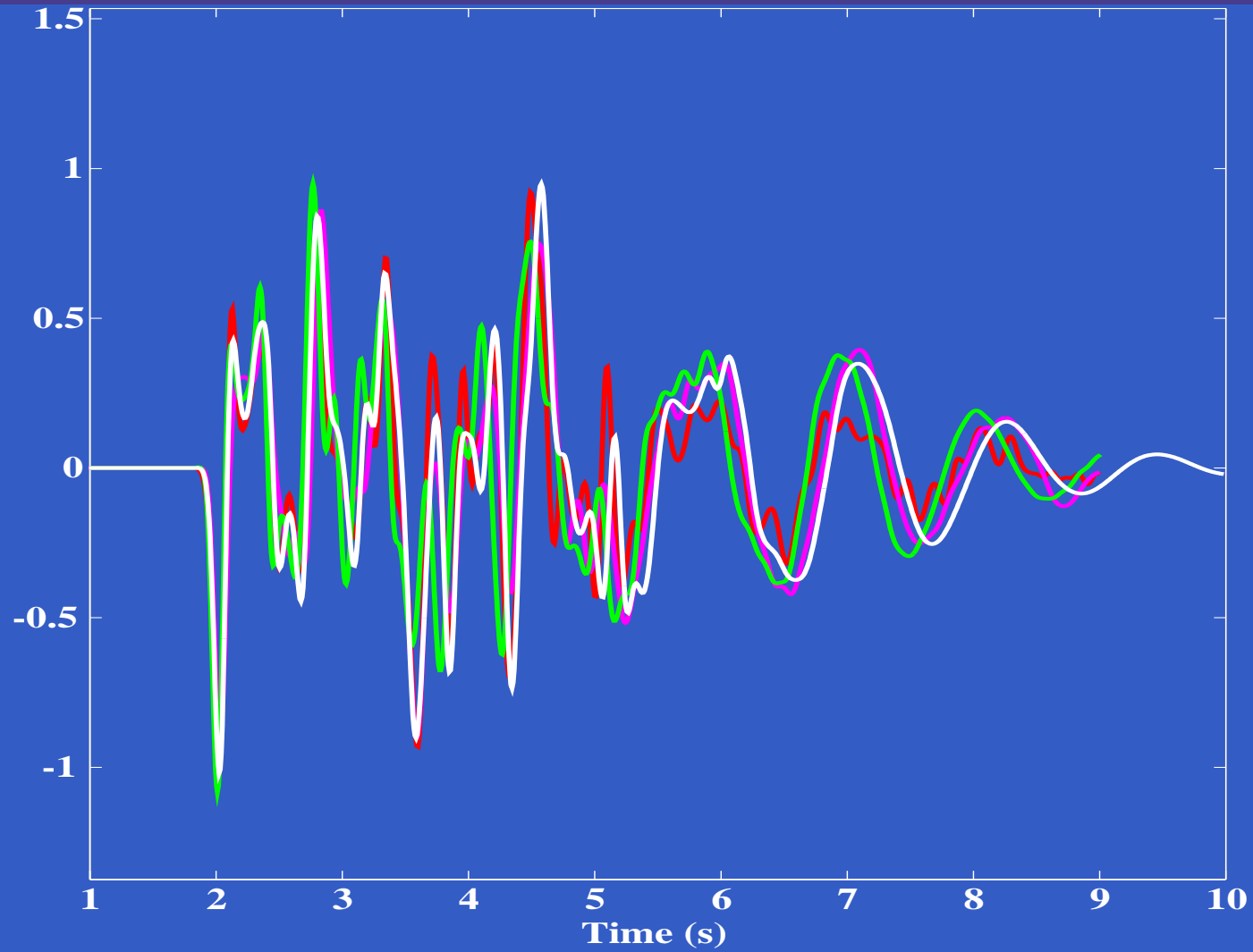


SCEC Benchmark LOH.3



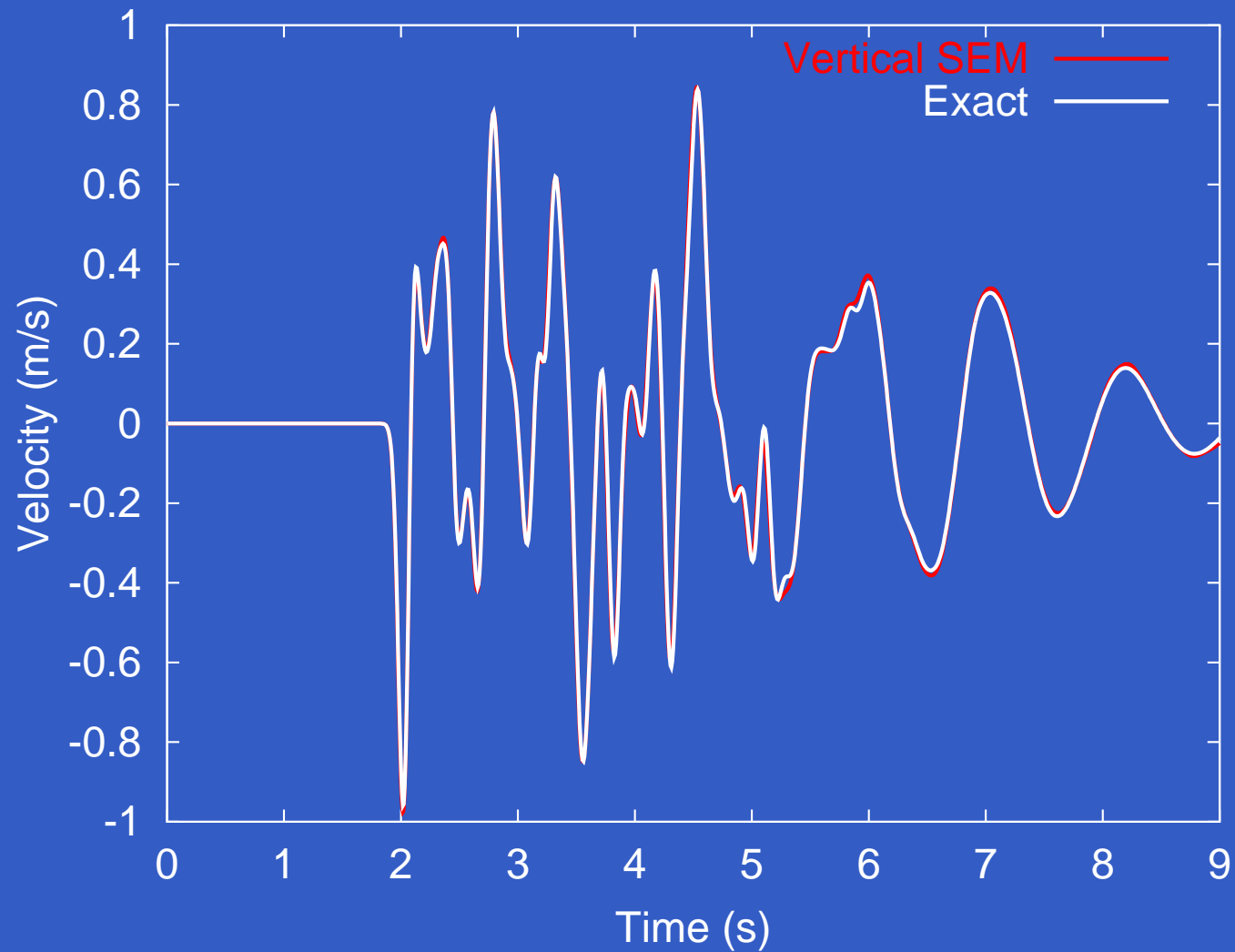
(Courtesy Steve Day)

SCEC Benchmark LOH.3



Vertical component FEM and FD (PEER Report)

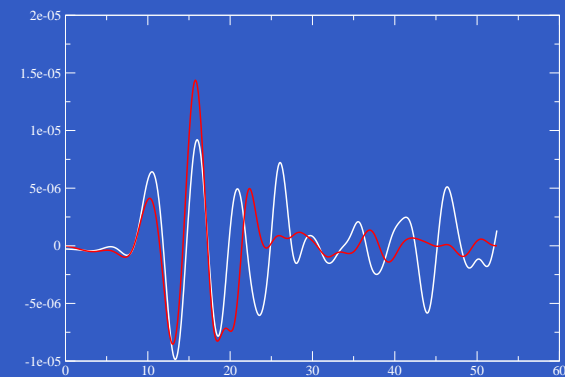
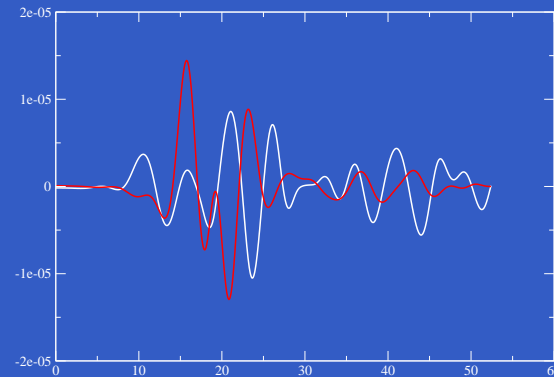
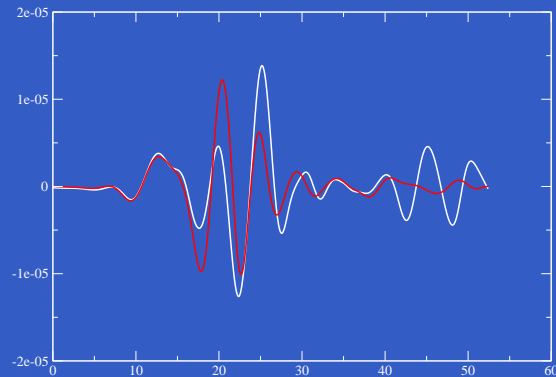
SCEC Benchmark LOH.3



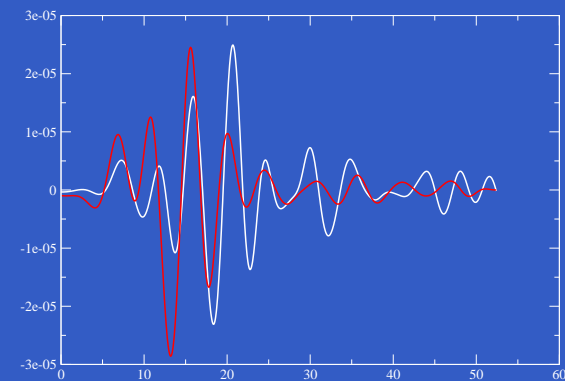
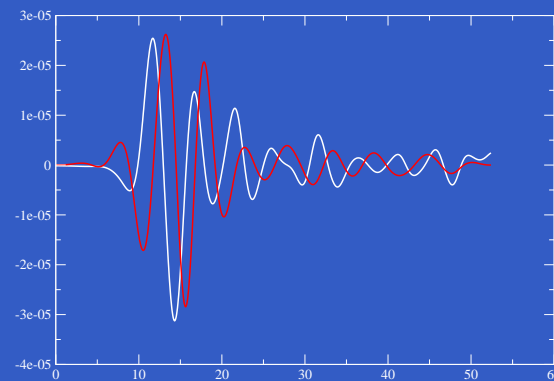
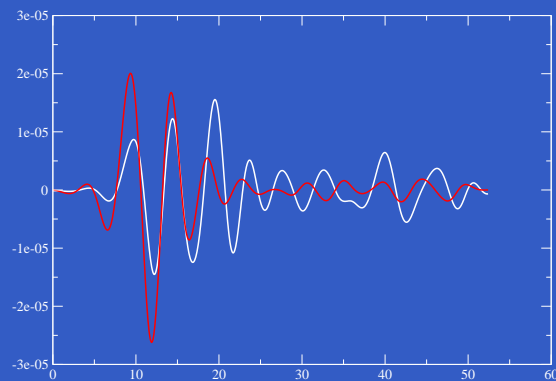
October 9, 2001, Hollywood



VCS (27° , 52 km)



MWC (61° , 34 km)

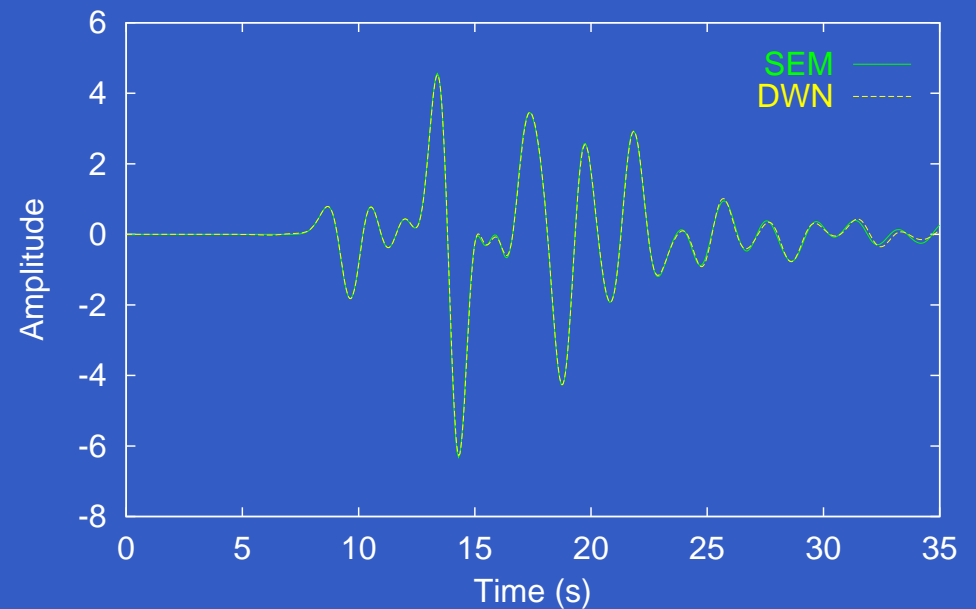


Vertical

Transverse

Radial

More Benchmarks

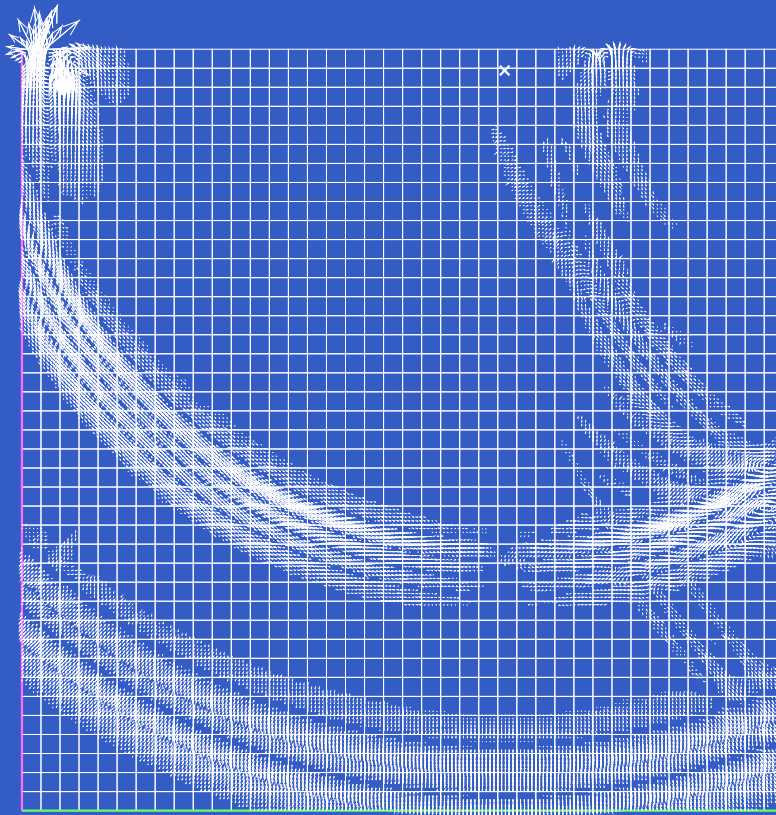


Komatitsch & Tromp (GJI, 139, 806-822, 1999)

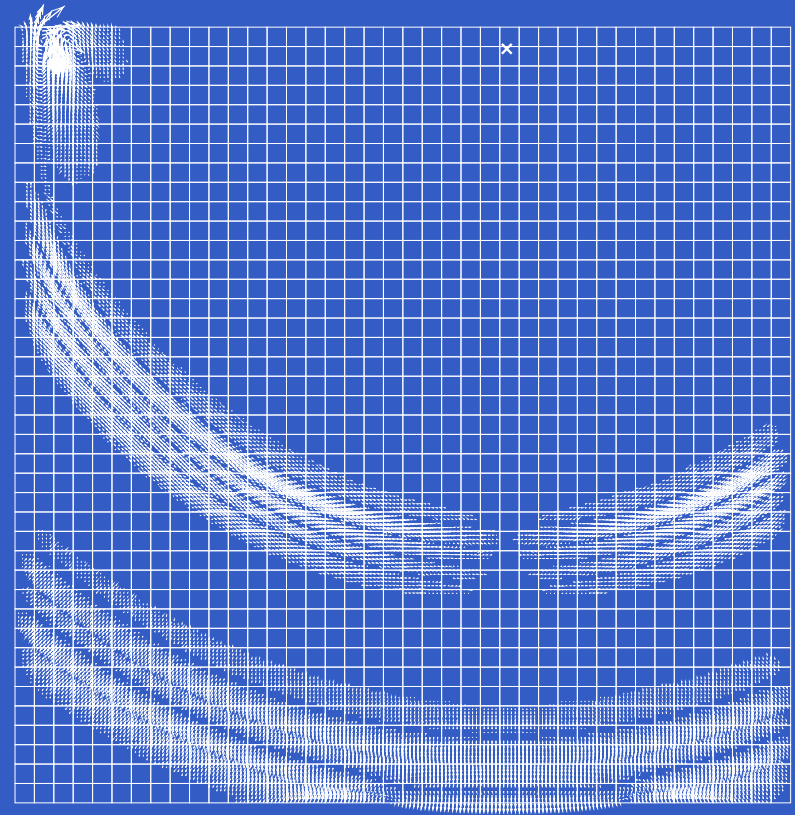
The Perfectly-Matched Layer



Clayton-Enquist



PML



Komatitsch & Tromp (1999)