Seismological constraints on the nature of cratonic lithosphere and Phanerozoic lithosphere

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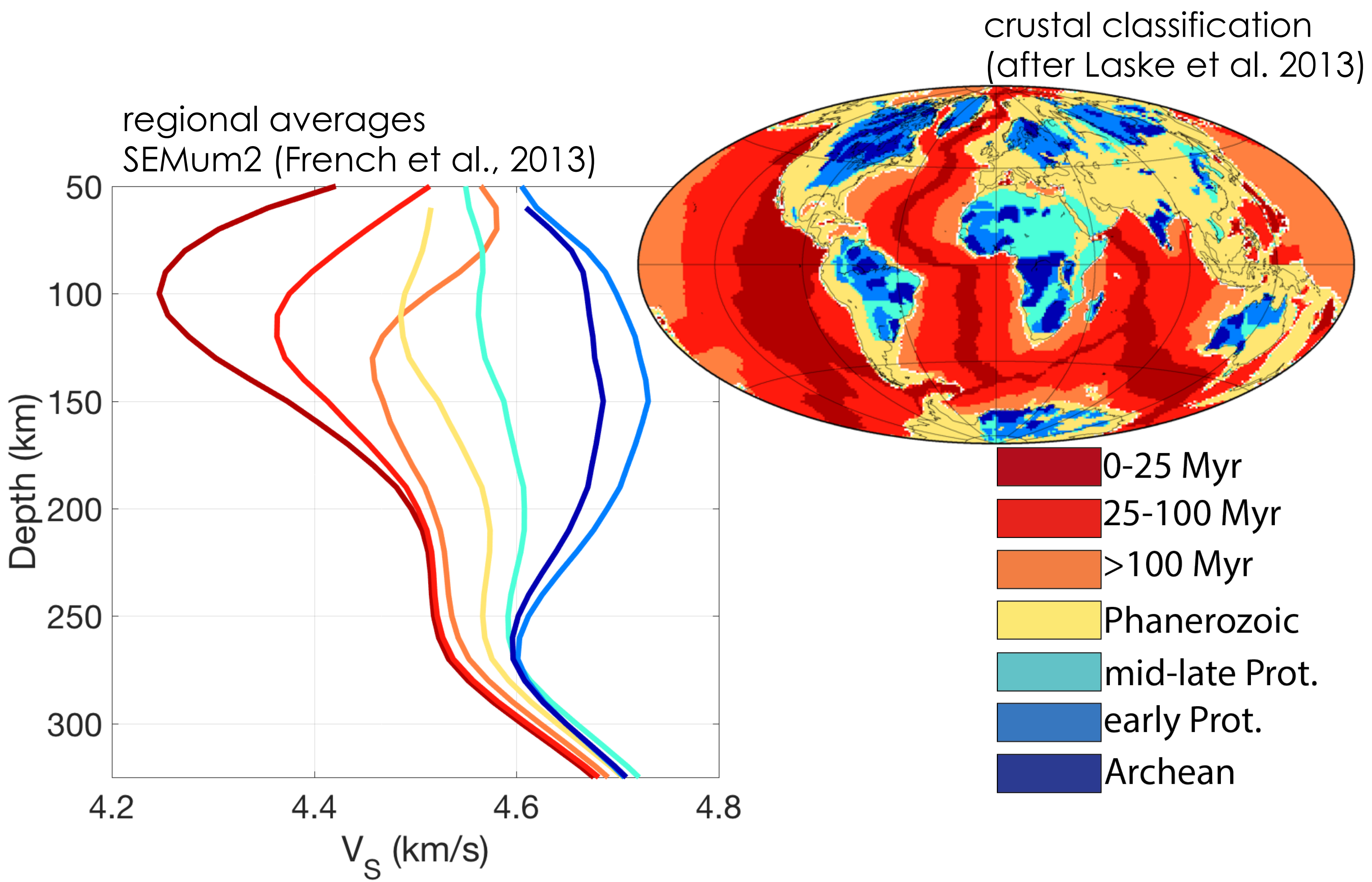
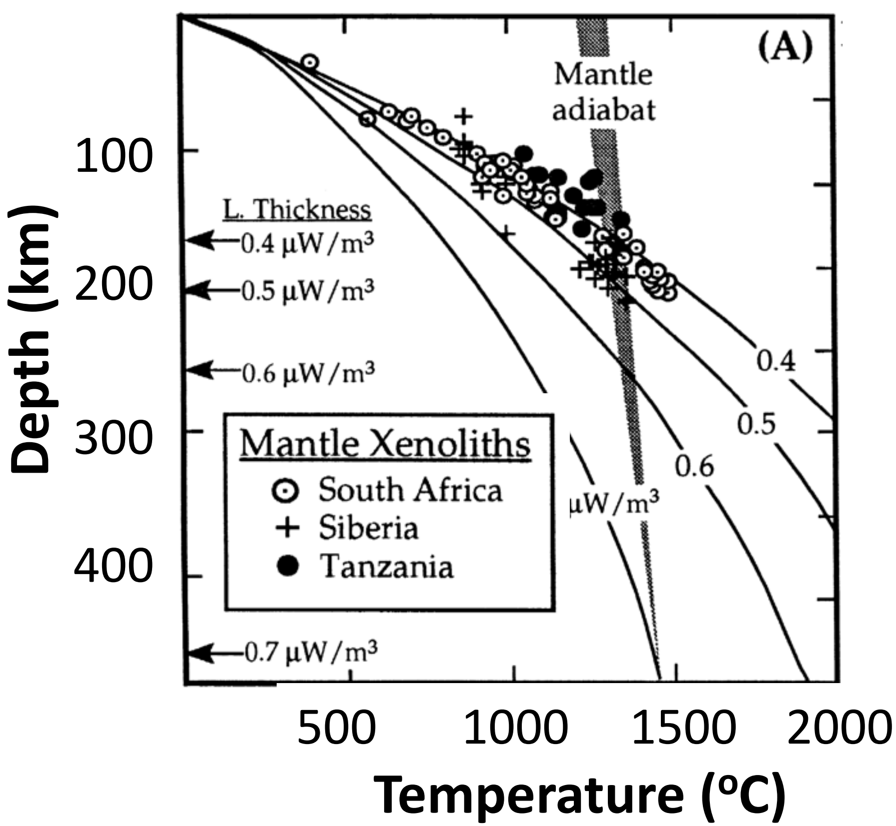
BROWN

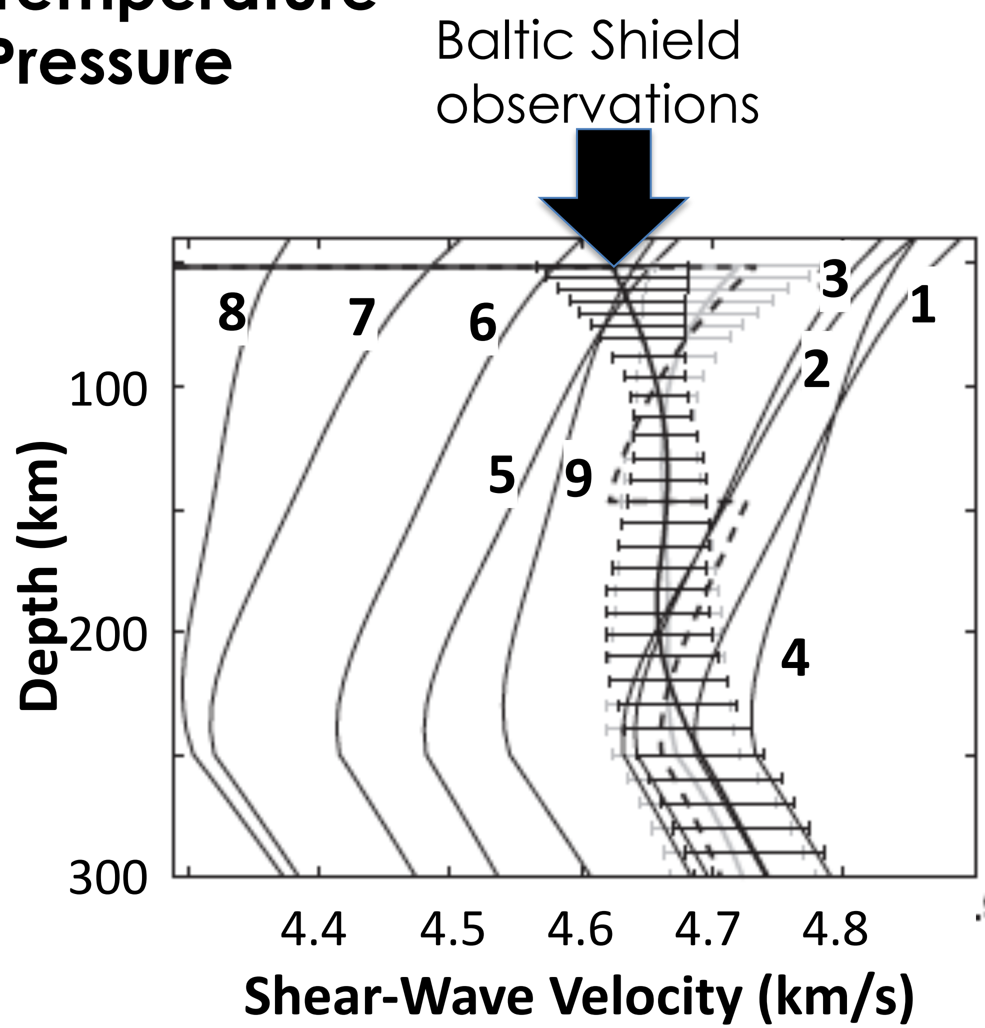
Global Seismic-Velocity Models



Effects of Temperature and Pressure

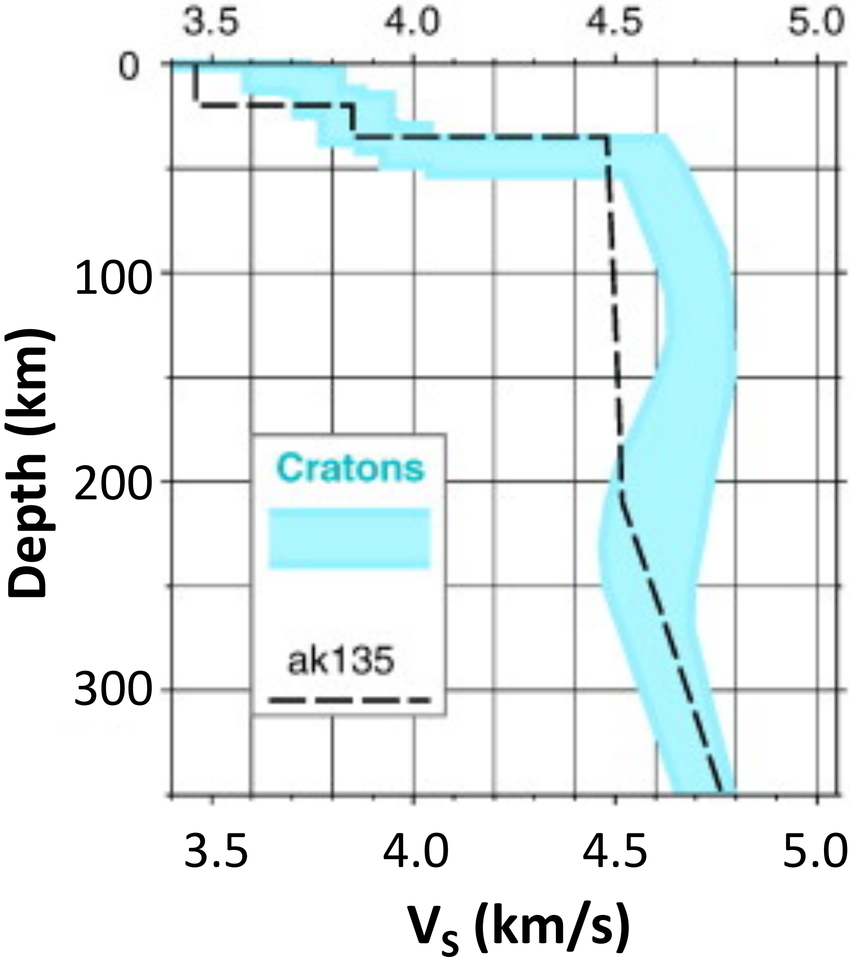


Rudnick et al. (2008)

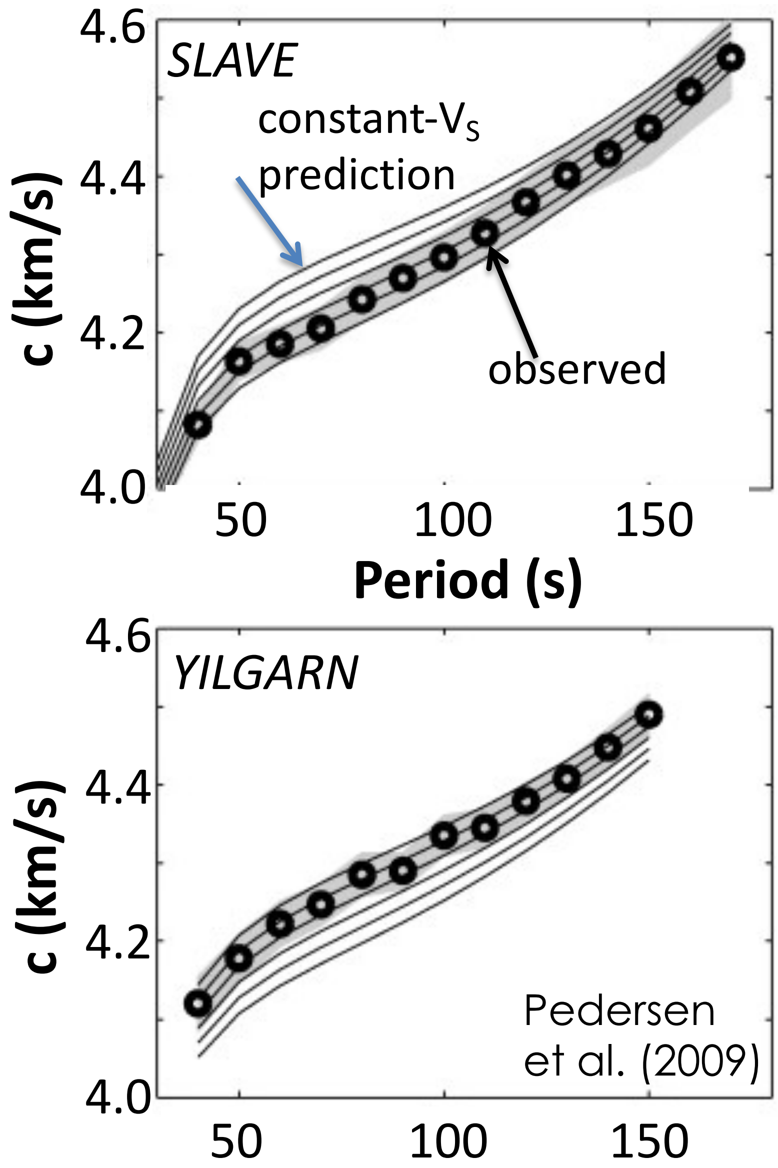


geotherm predictions:
1-3: xenolith peridotites
4,5: wehrlite, websterite
6-9: exotic compositions
(Bruneton et al., 2004)

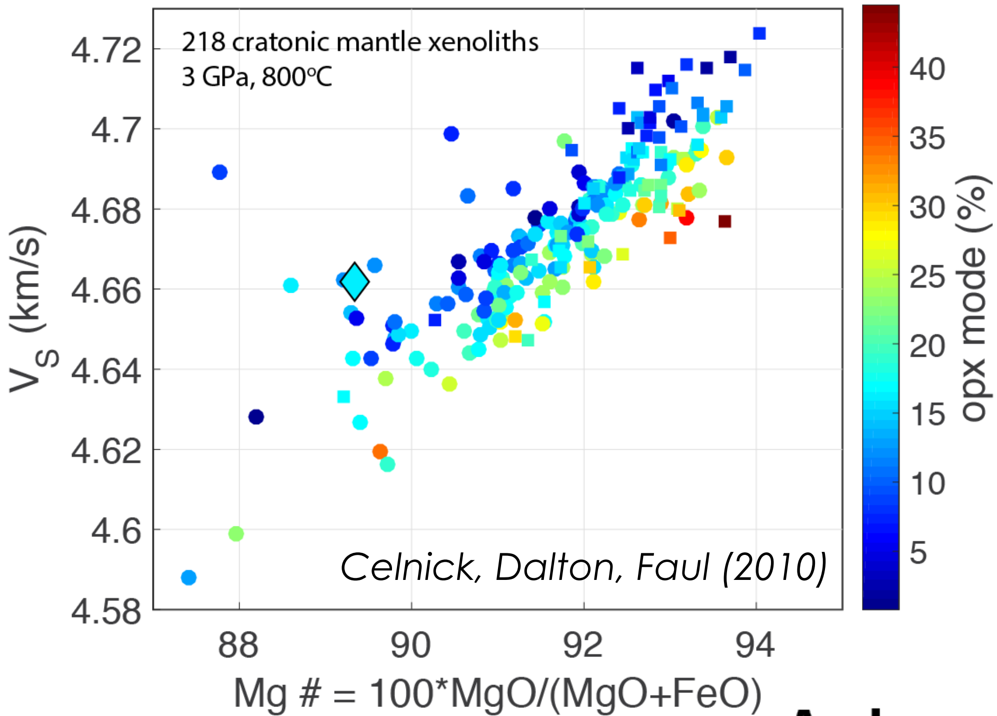
Surface-Wave Observations of Cratonic Lithosphere



Lebedev et al. (2009)

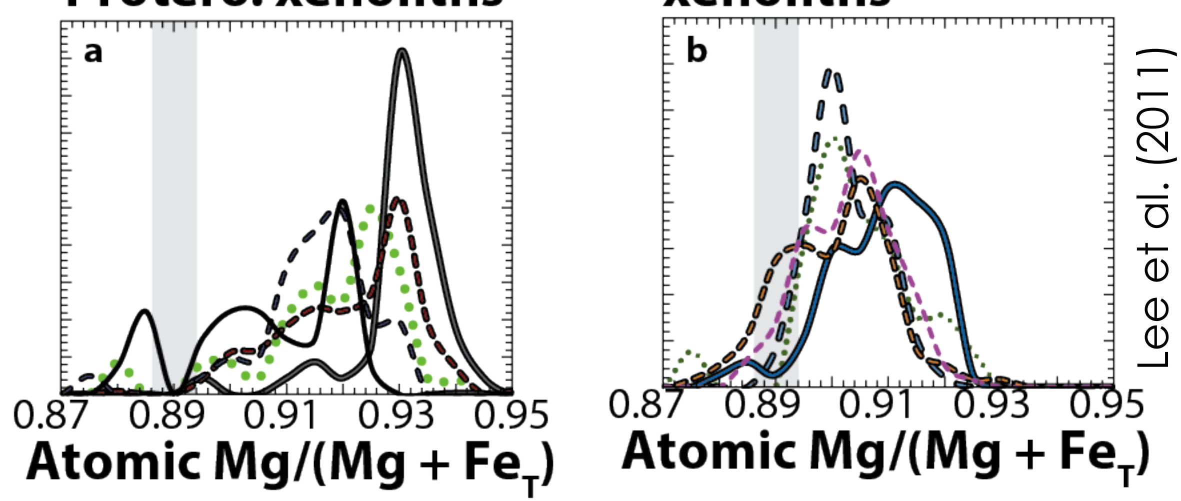


Effects of Composition

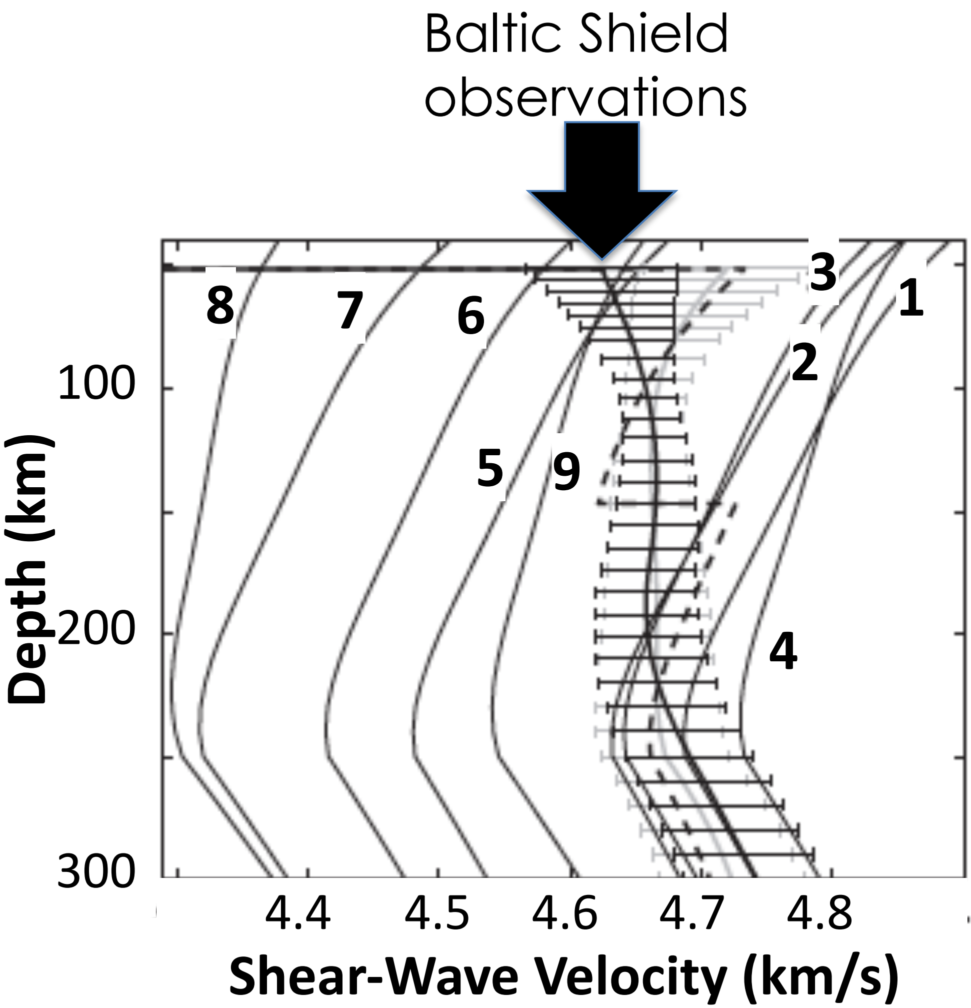


Archean & Protero. xenoliths

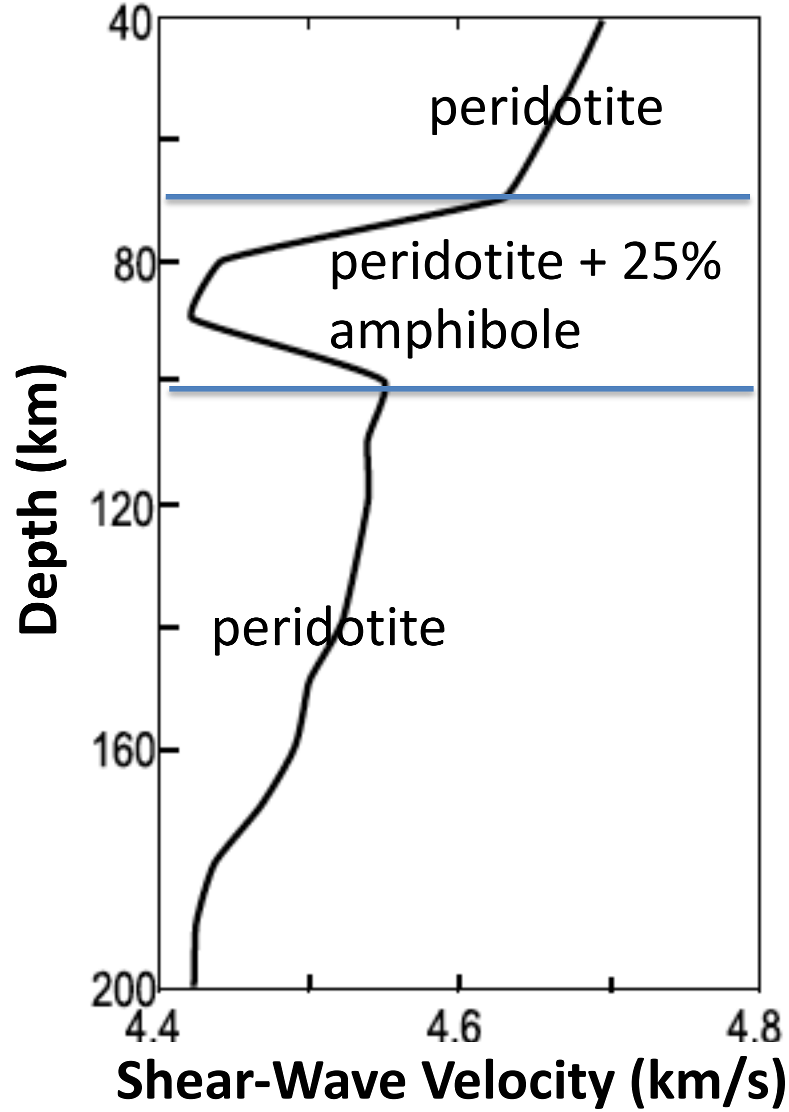
Phanerozoic xenoliths



Effects of Composition

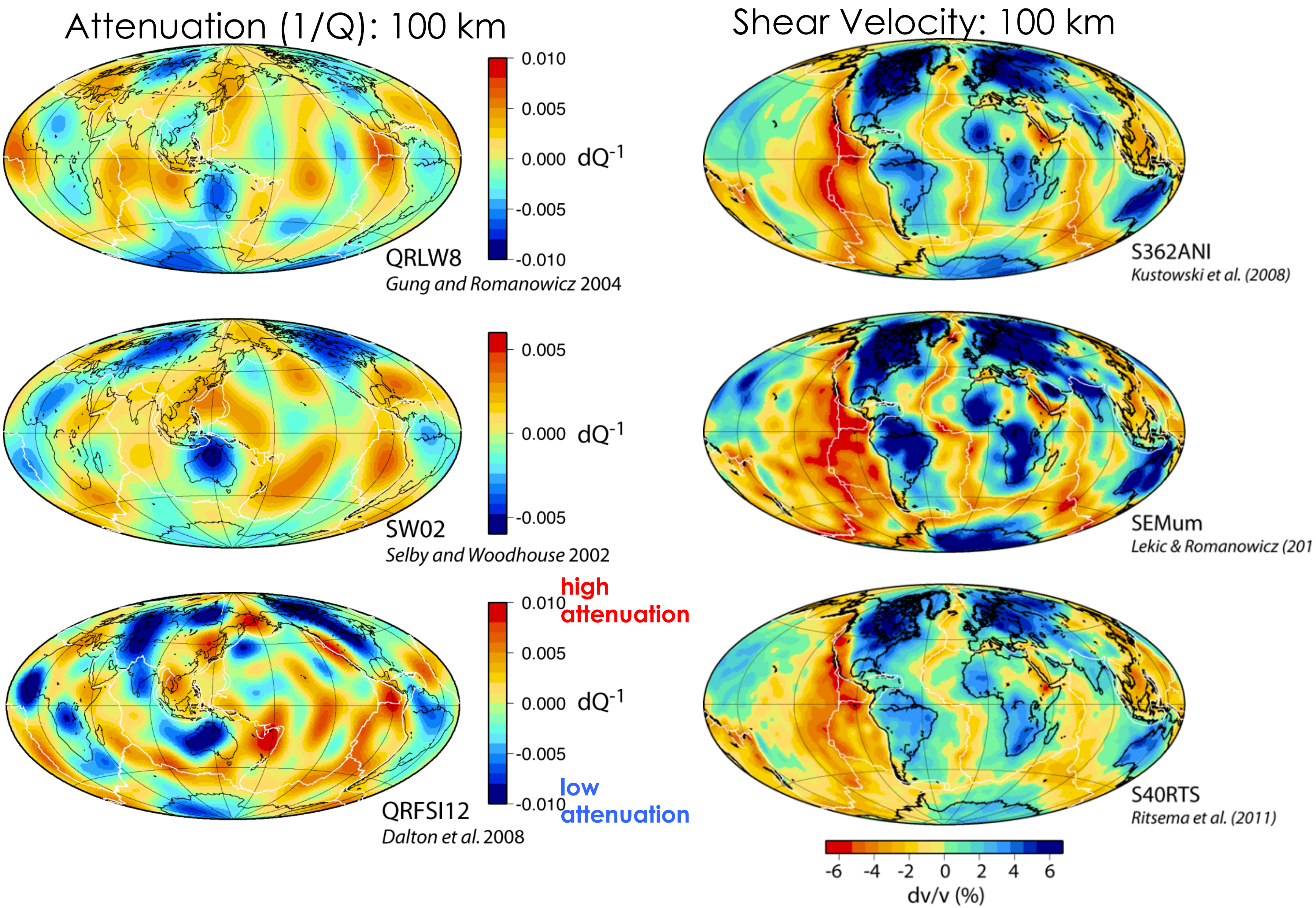


1-3: xenolith peridotites
6: peridotite + 4% amphibole
7: peridotite + 10% amphibole
8: peridotite + 13% phlogopite
(Bruneton et al., 2004)



Selway et al. (2015)

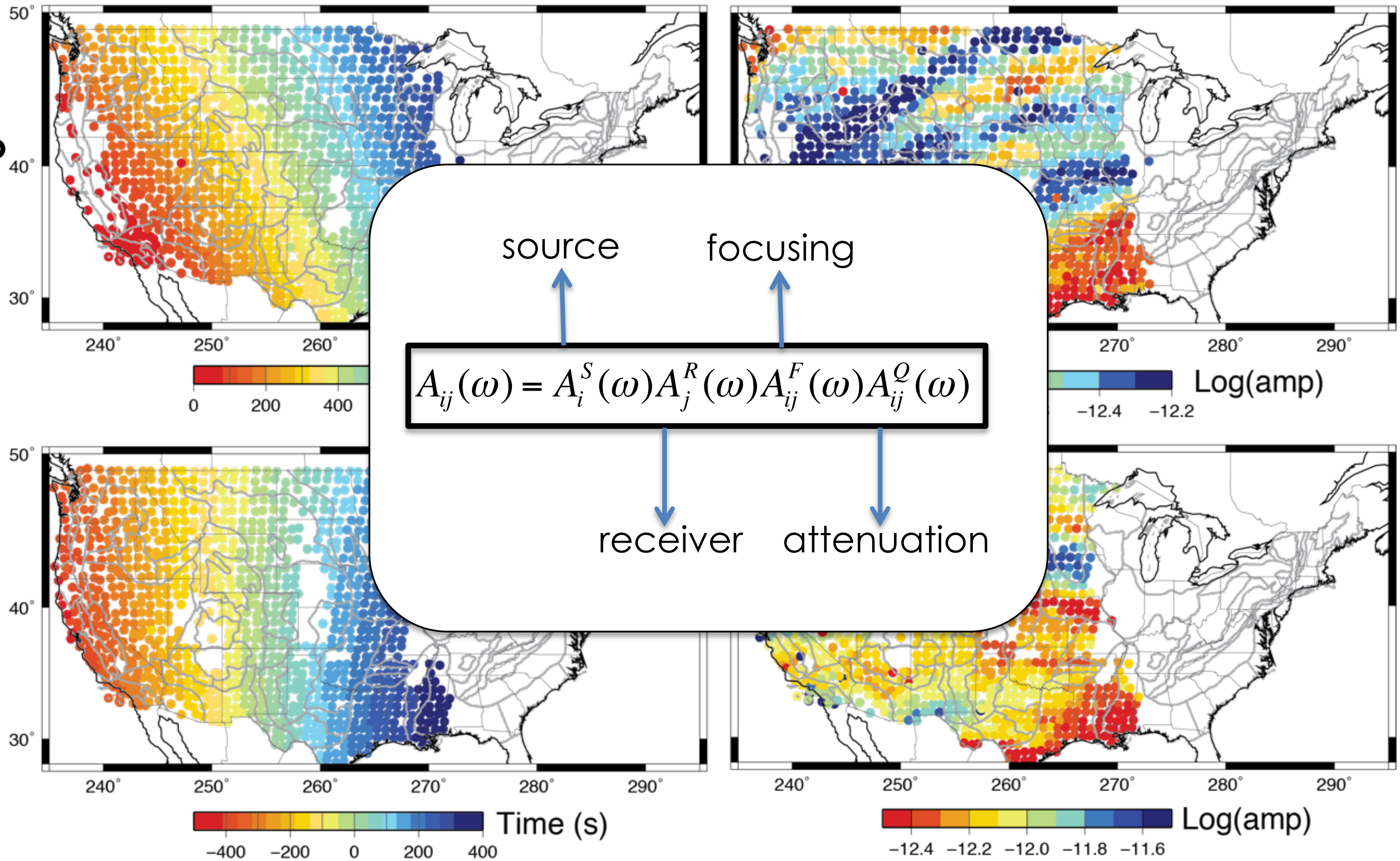
Status of Global Attenuation Models as of 2015



travel times more straightforward than amplitudes

Composite Fields of Observations of 50-s Rayleigh Waves

Travel-time field | **Amplitude field**



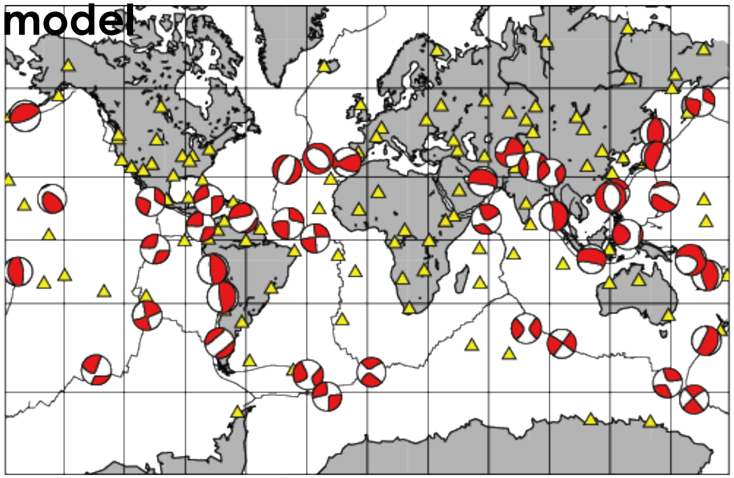
3 events to southwest (Samoan Islands)

3 events to west (Solomon Islands)

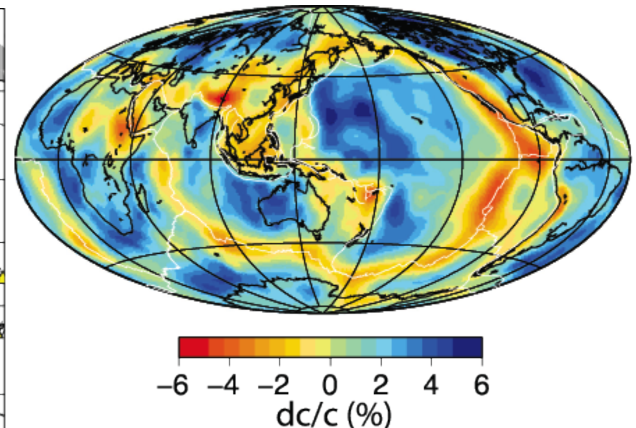
Wavefield Simulations

SPECFEM3D_GLOBE (Komatitsch and Tromp, 2002a; 2002b)

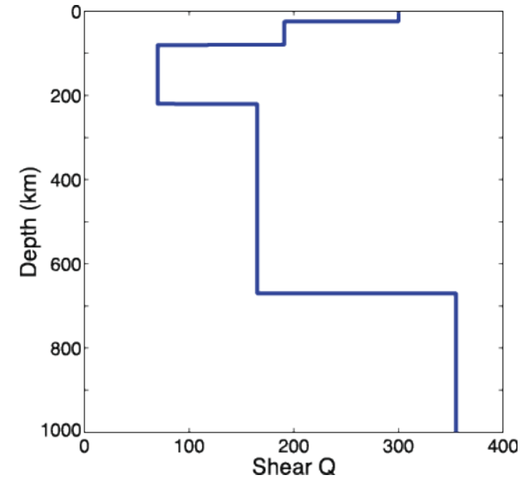
42 shallow events, 134 global stations



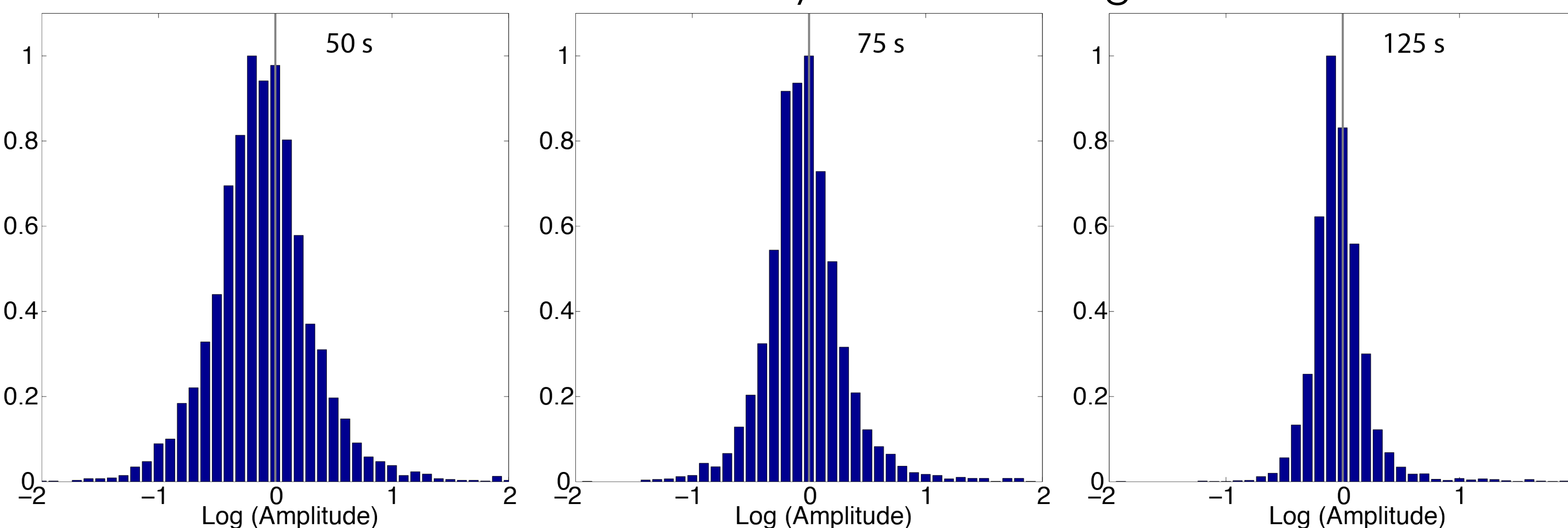
3-D elastic model



1-D anelastic model

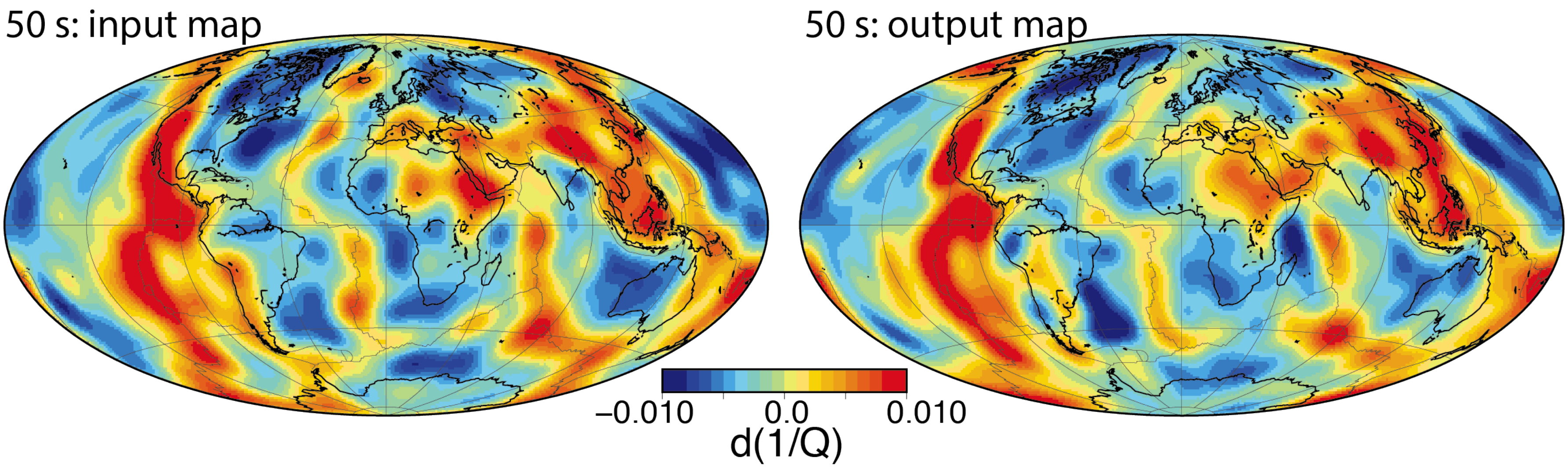


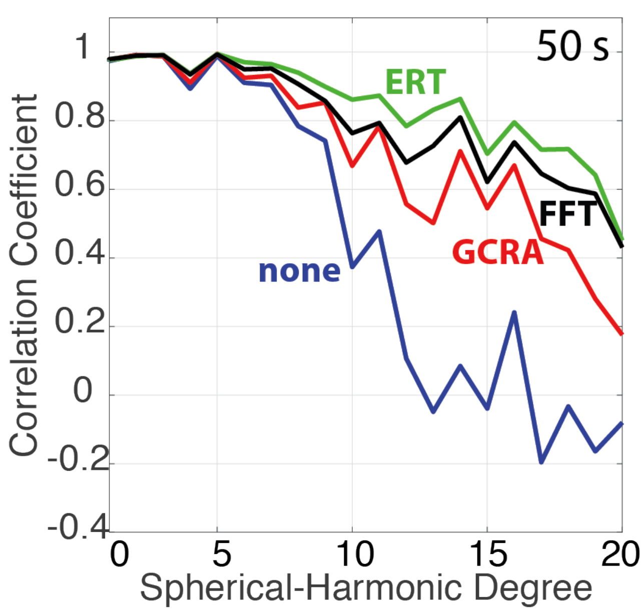
measurements of synthetic seismograms



Dalton et al. (GJI, 2014)

Wavefield Simulations: Focusing Effects

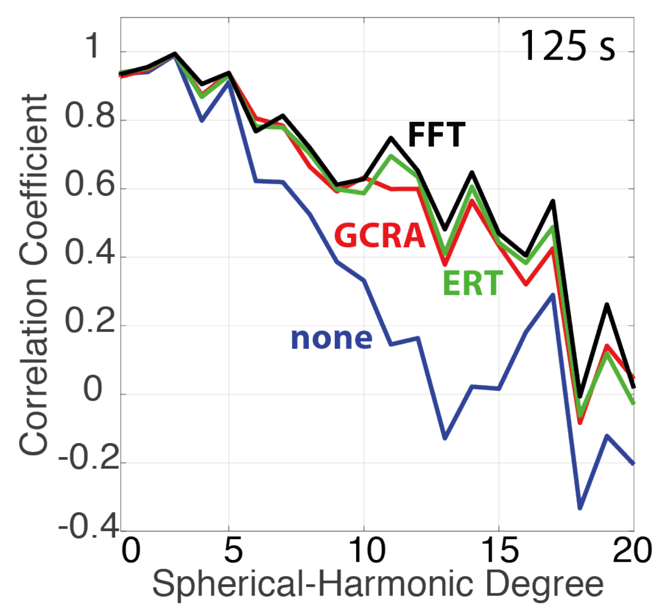




GCRA: great-circle ray approx.

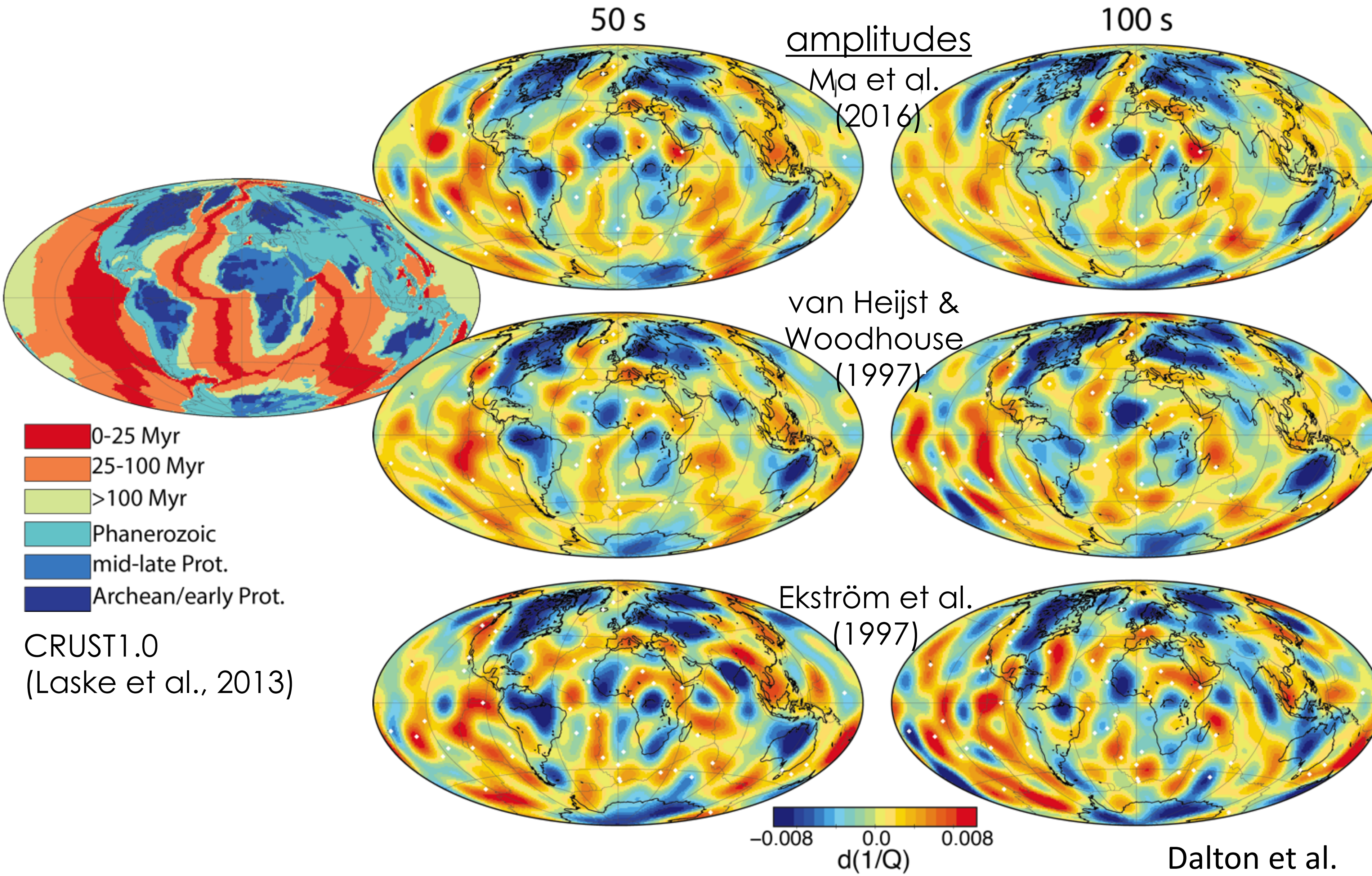
ERT: exact ray theory

FFT: finite-frequency theory



Dalton et al. (*EPSL*, 2017)

2-D Attenuation Maps



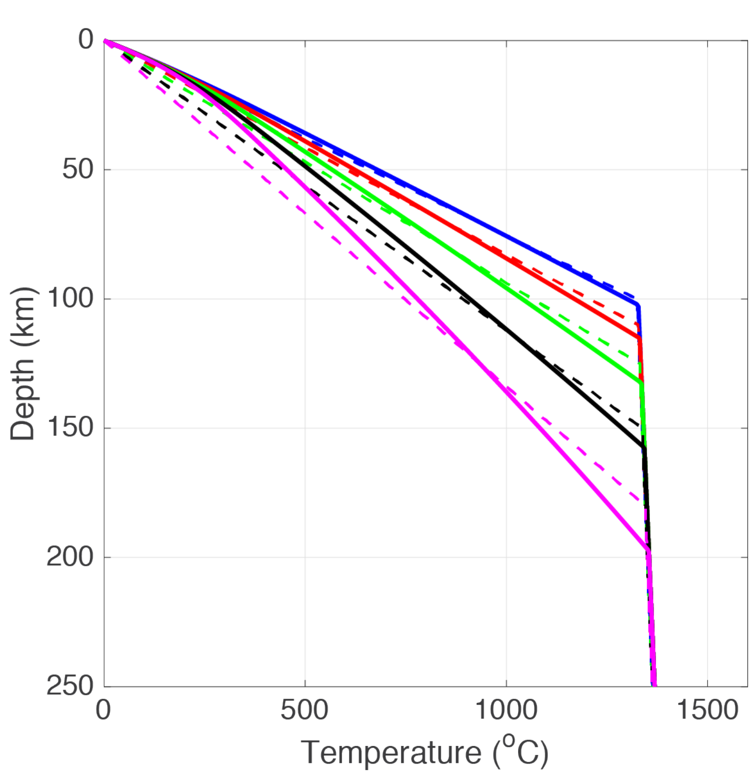
Dalton et al. (*EPSL*, 2017)

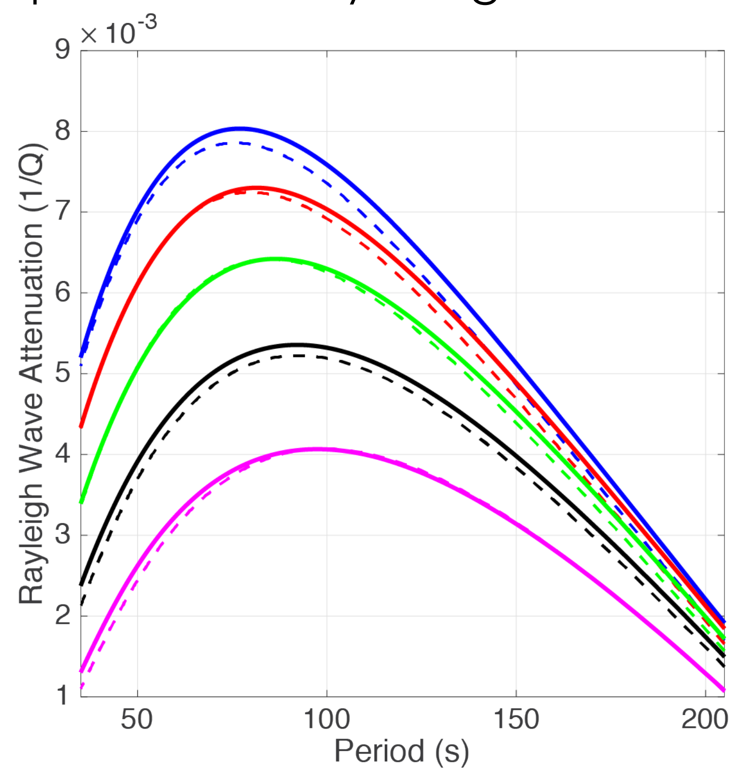
Thermal Structure

1. Construct geotherms by systematically varying:
   - ❑ potential temperature (T_P) of adiabat (1100°C,1150°C,1200°C,… 1600°C)
   - ❑ layer thickness (5 km, 10 km, 15 km, 20 km, … , 400 km)

2. Convert temperature into shear attenuation and seismic velocity using Jackson and Faul (2010)

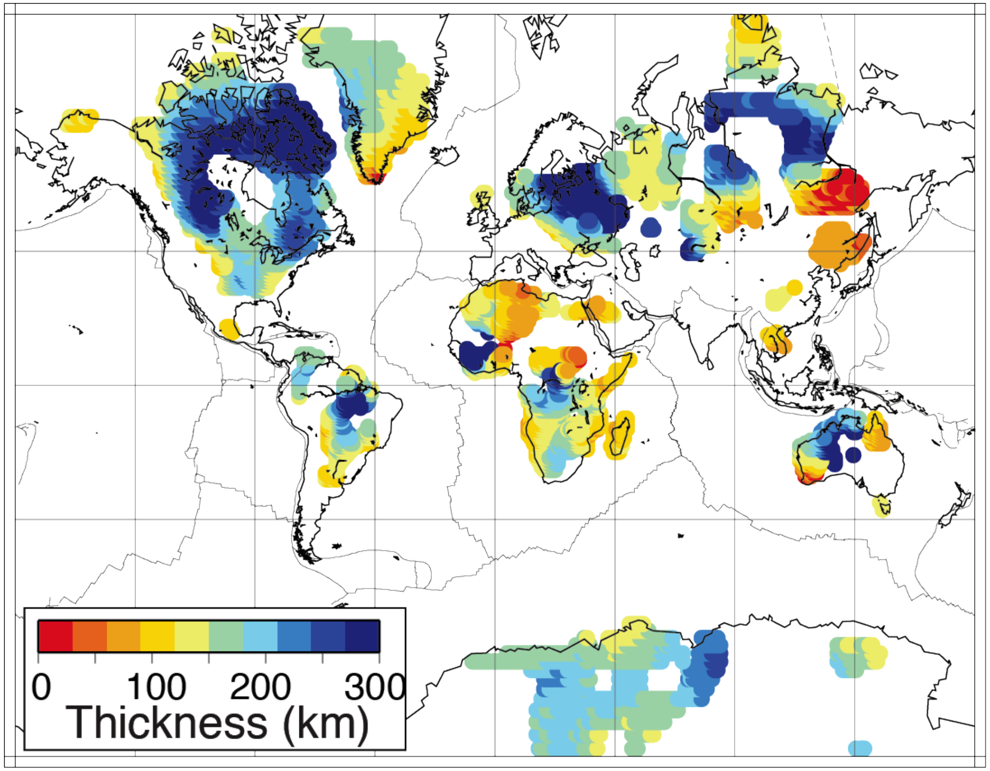
3. Predict Rayleigh wave attenuation and phase velocity using Mineos

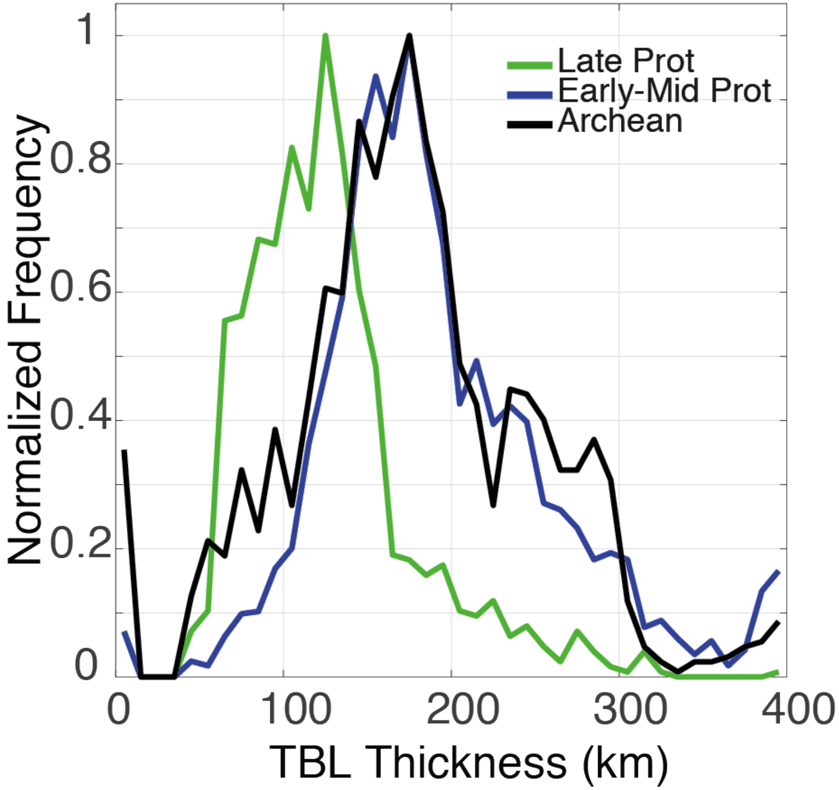




Thermal Structure

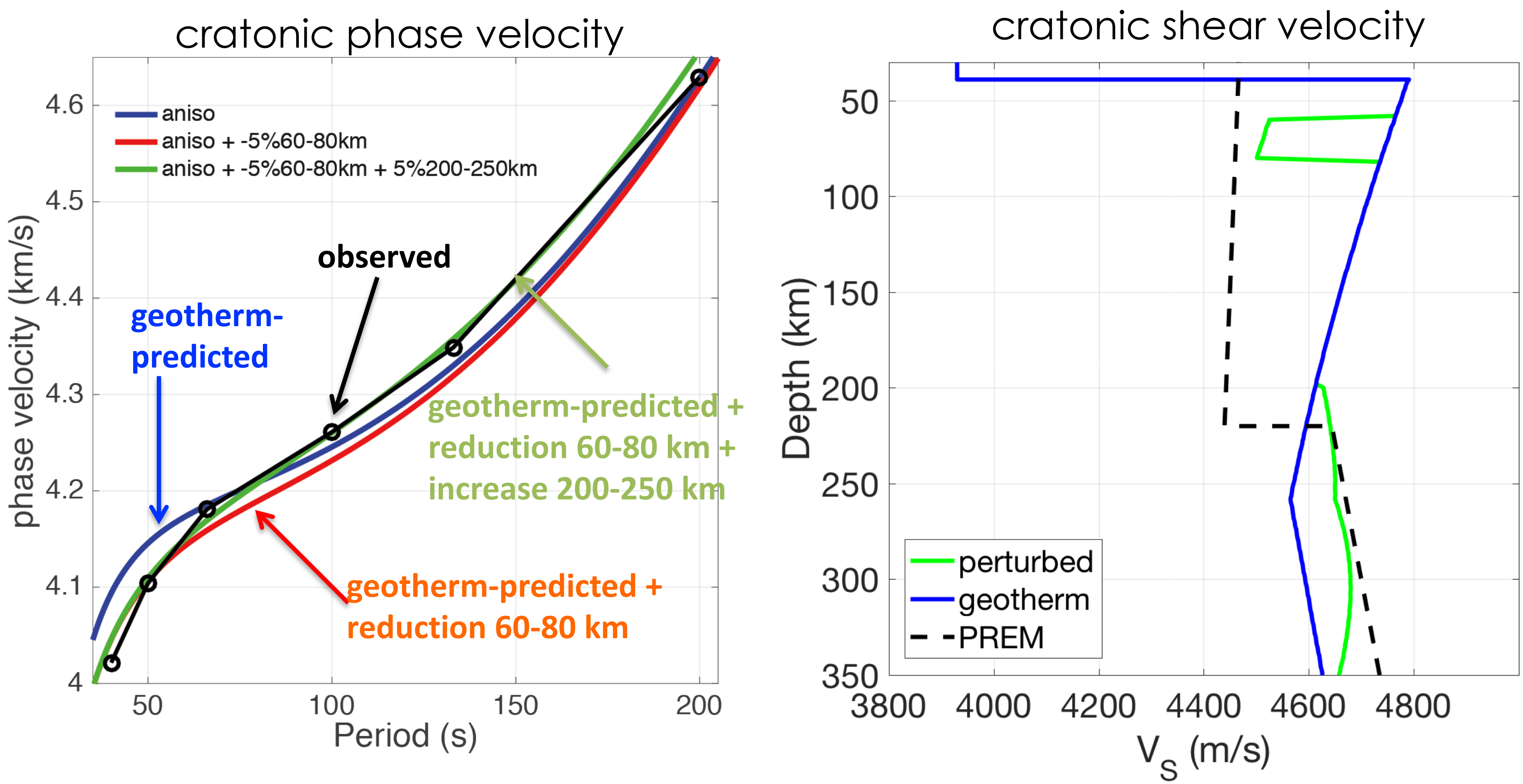
Fit to 2-D Rayleigh wave attenuation maps: 40-200s



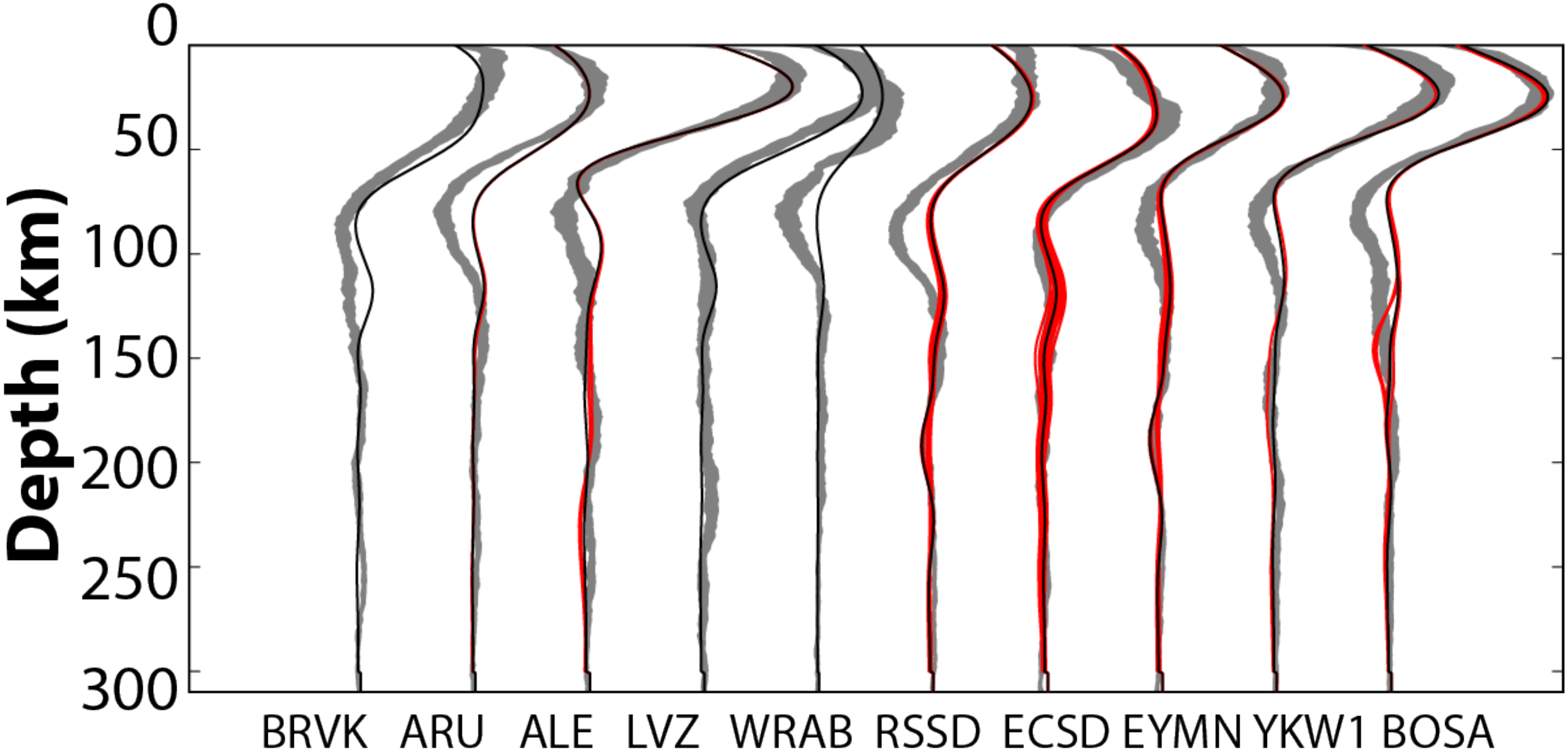


Dalton et al.
(*EPSL*, 2017)

Thermal Structure

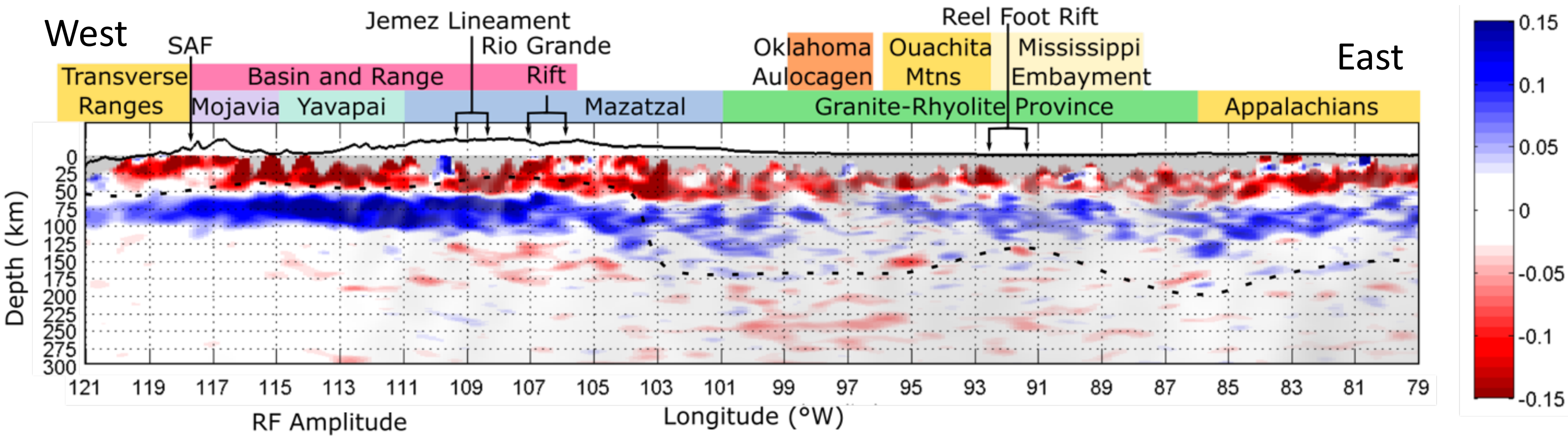


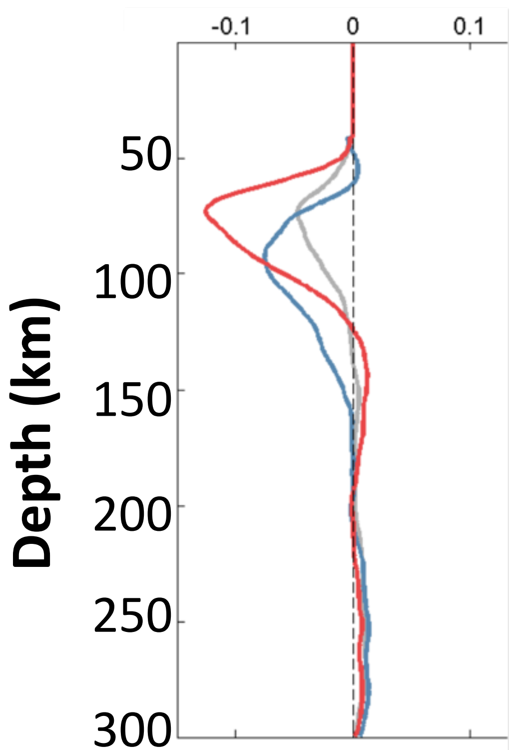
Single-Station Sp Profiles from Global Cratons

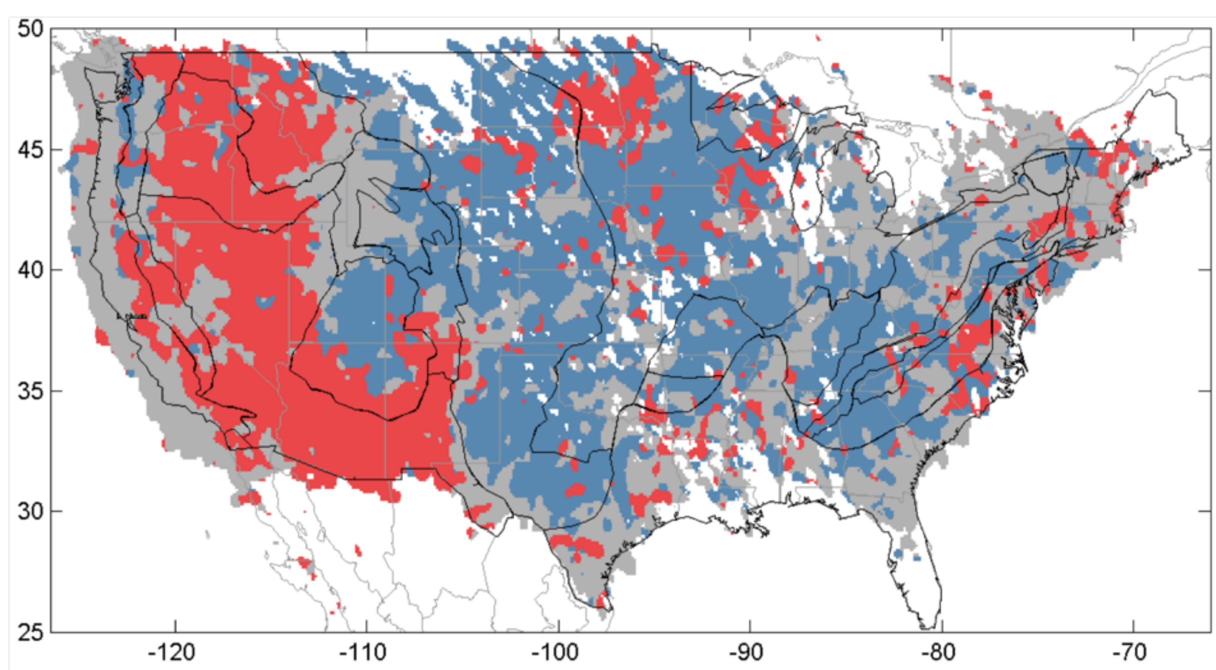


Mancinelli, Fischer,
Dalton (in revision)

CCP Sp Profiles from USArray Stations

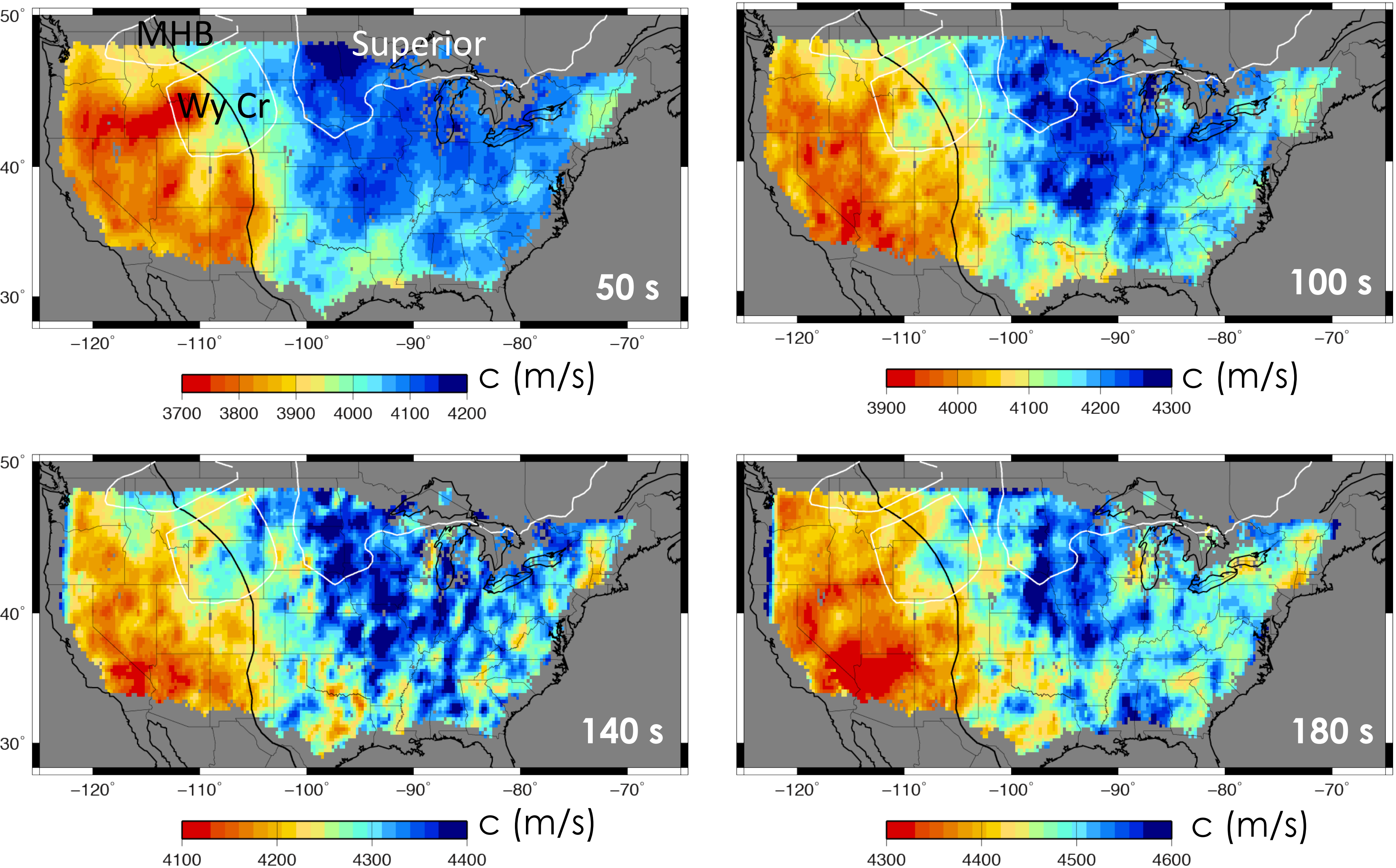






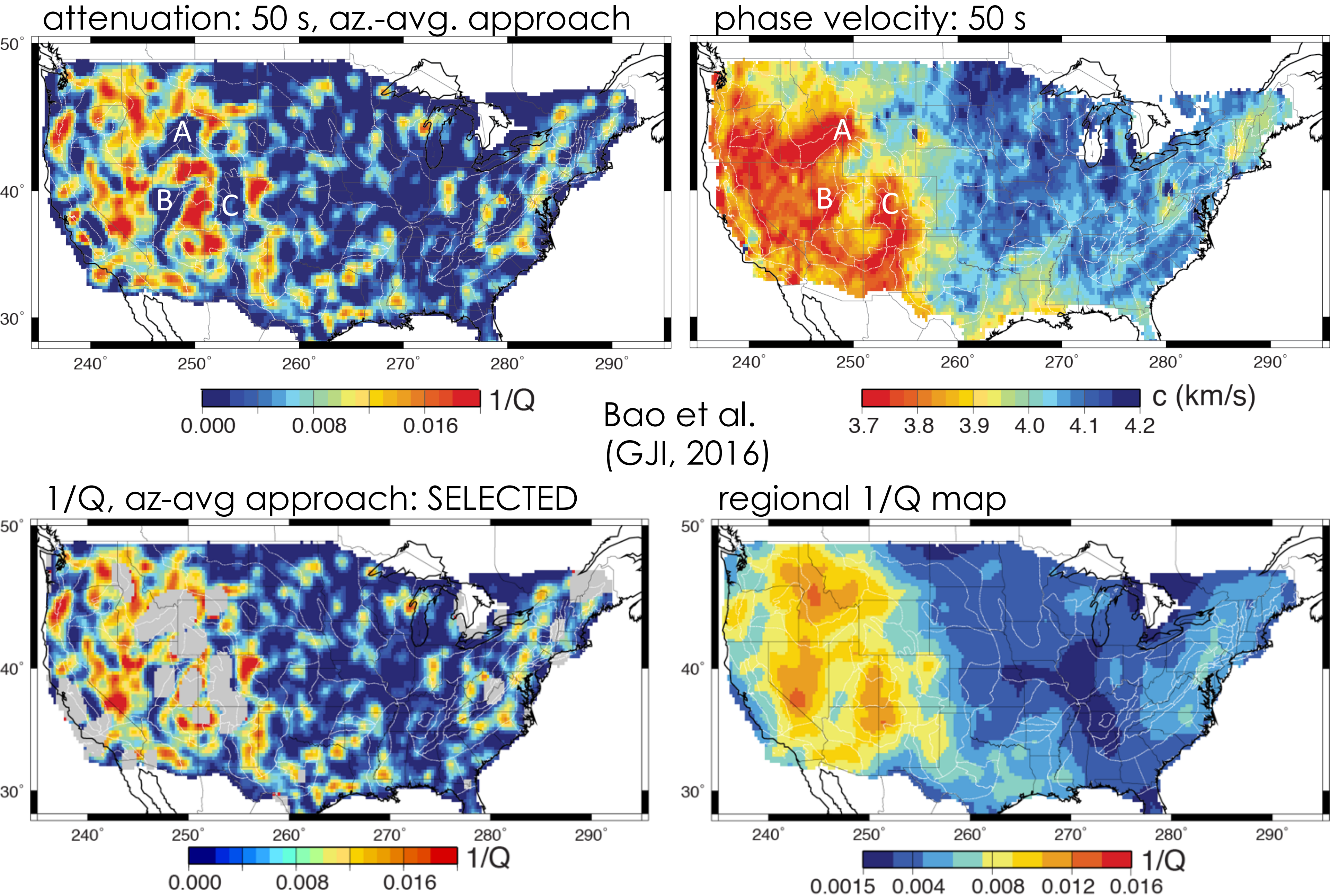
Hopper & Fischer (in prep.)

Rayleigh Wave Phase-Velocity Maps



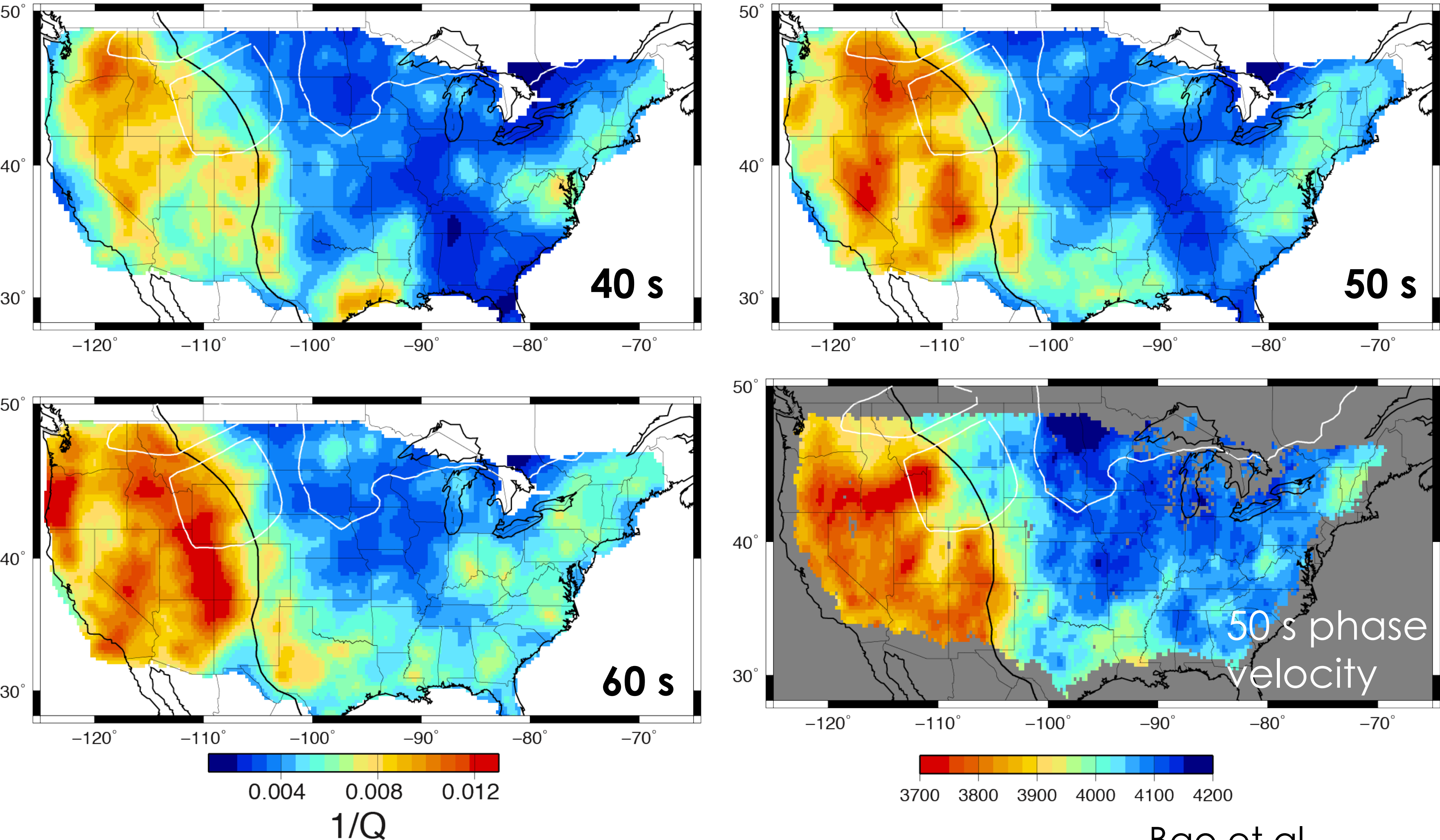
**province boundaries from Andrew Schaeffer

Areas of Anomalous Attenuation



Bao et al. (GJI, 2016)

Regionally Averaged Attenuation Maps



Bao et al. (GJI, 2016)

Conclusions

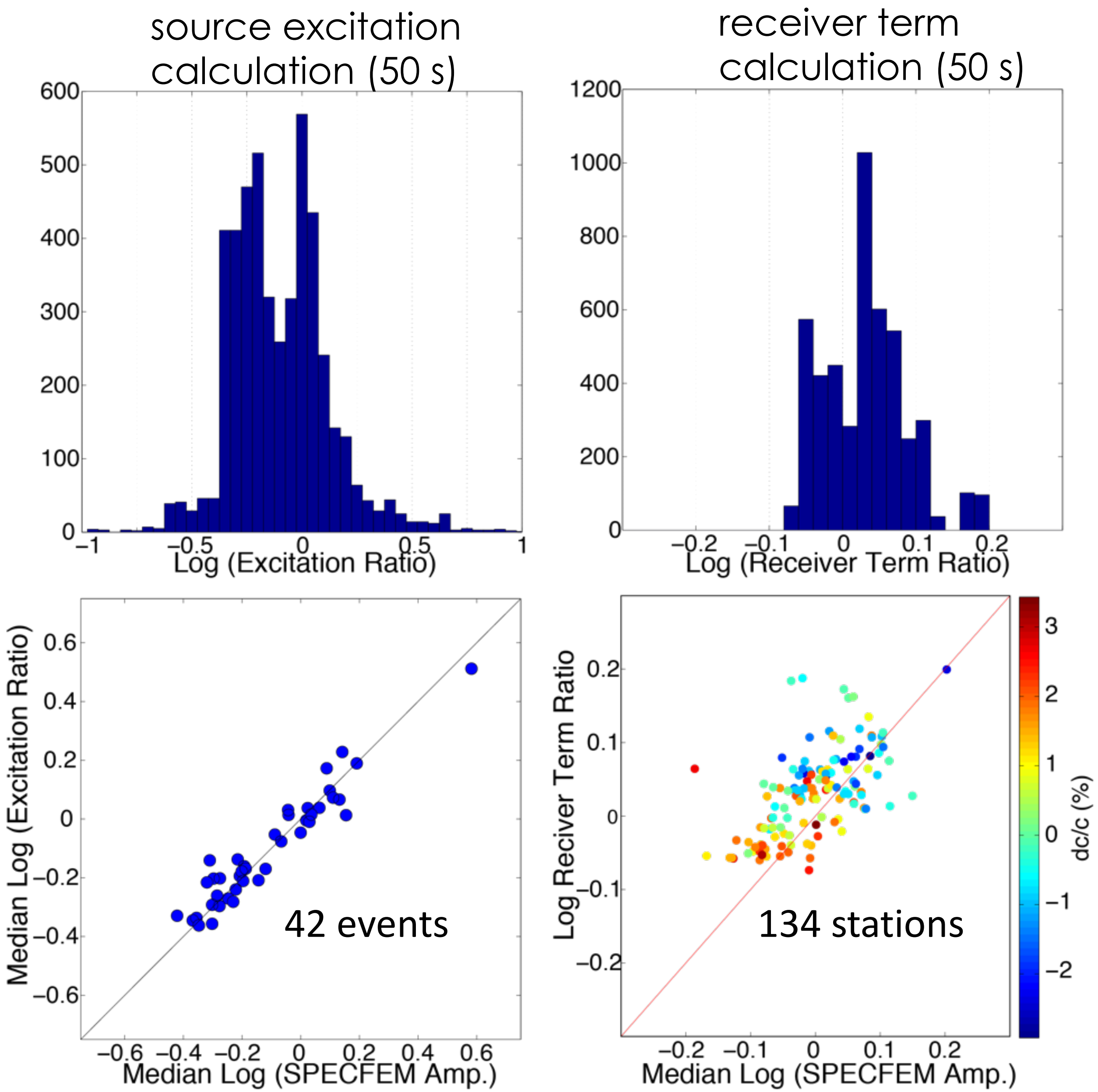
1. New global degree-16 attenuation maps
    - strong agreement using different amplitude data sets and focusing corrections
    - clearly image very low attenuation associated with specific continental cratons.

2. Frequency-dependent attenuation values at periods < 200 s are fit by a simple thermal boundary layer.
    - global variations in cratonic LAB depth
    - allows the compositional effects on shear velocity to be isolated

3. USArray attenuation maps
    - high attenuation west
    - low attenuation interior
    - elevated attenuation in northeast

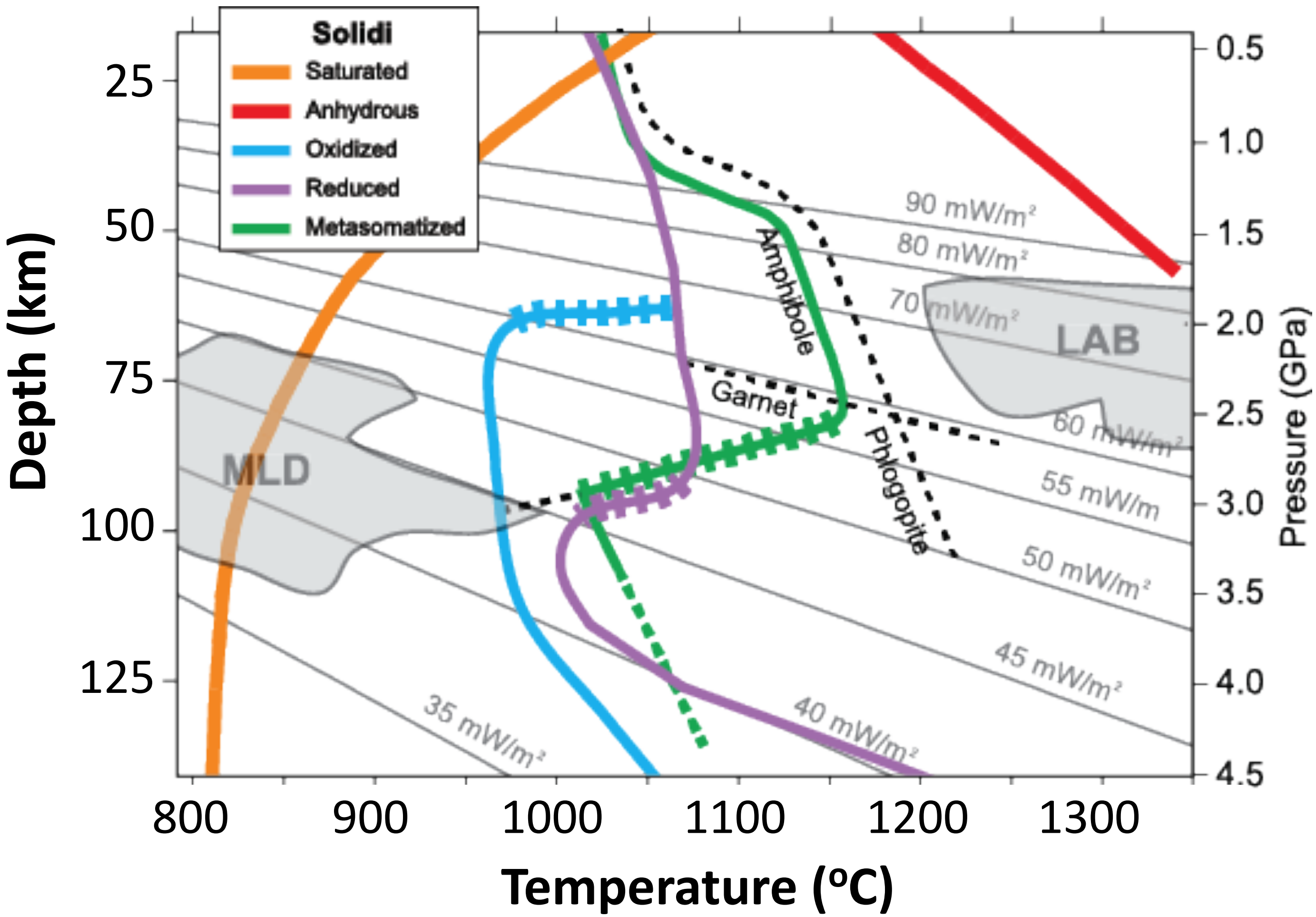
4. Anomalous features in attenuation maps demand future investigation
    - focusing effects underestimated?
    - other wave-propagation phenomena?

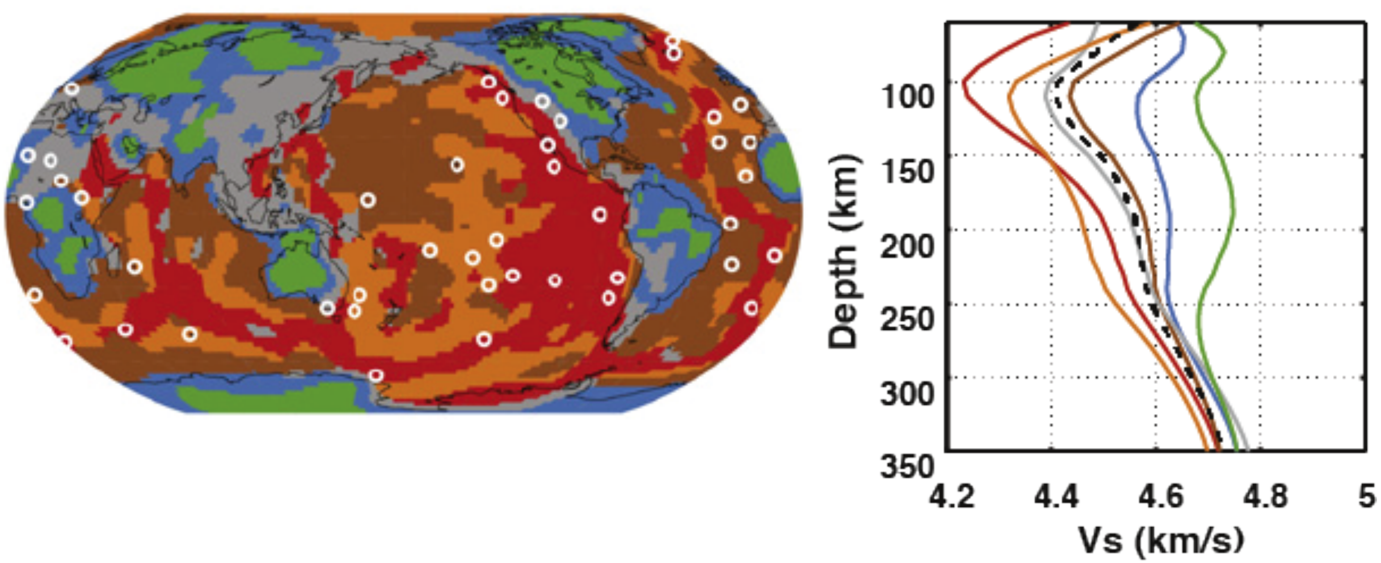
Wavefield Simulations: Source and Receiver



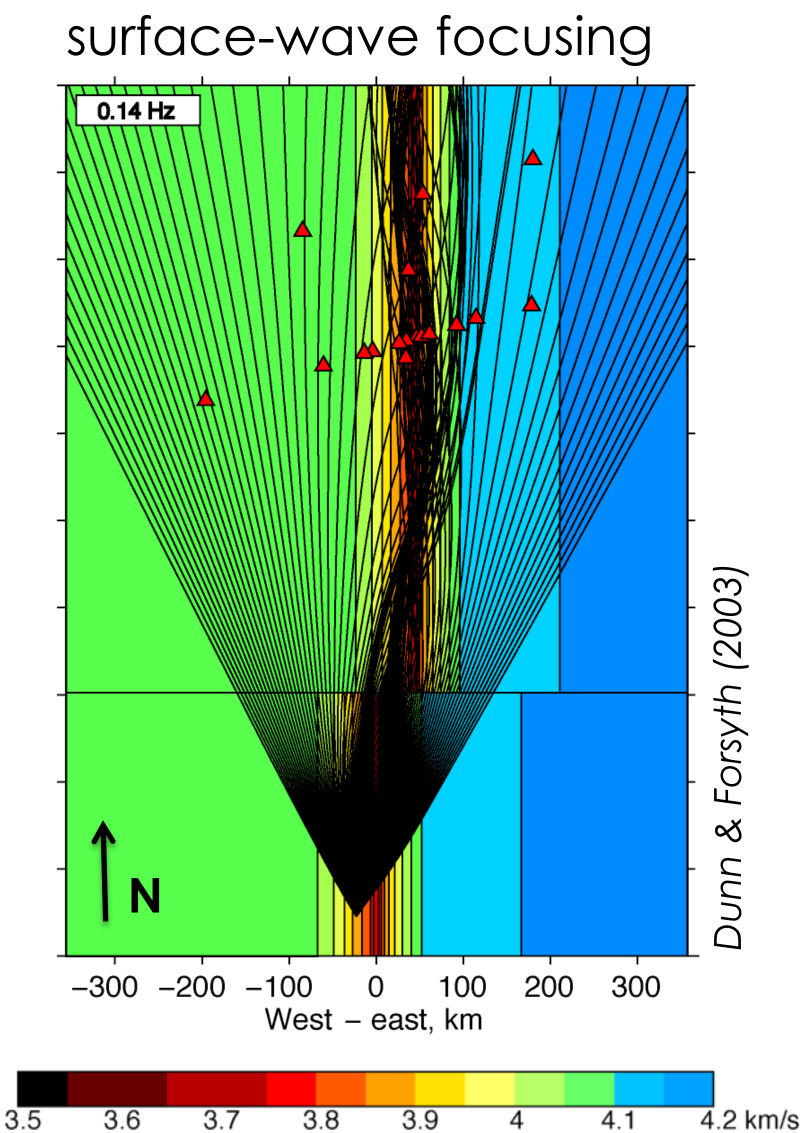
Dalton et al. (*GJI*, 2014)

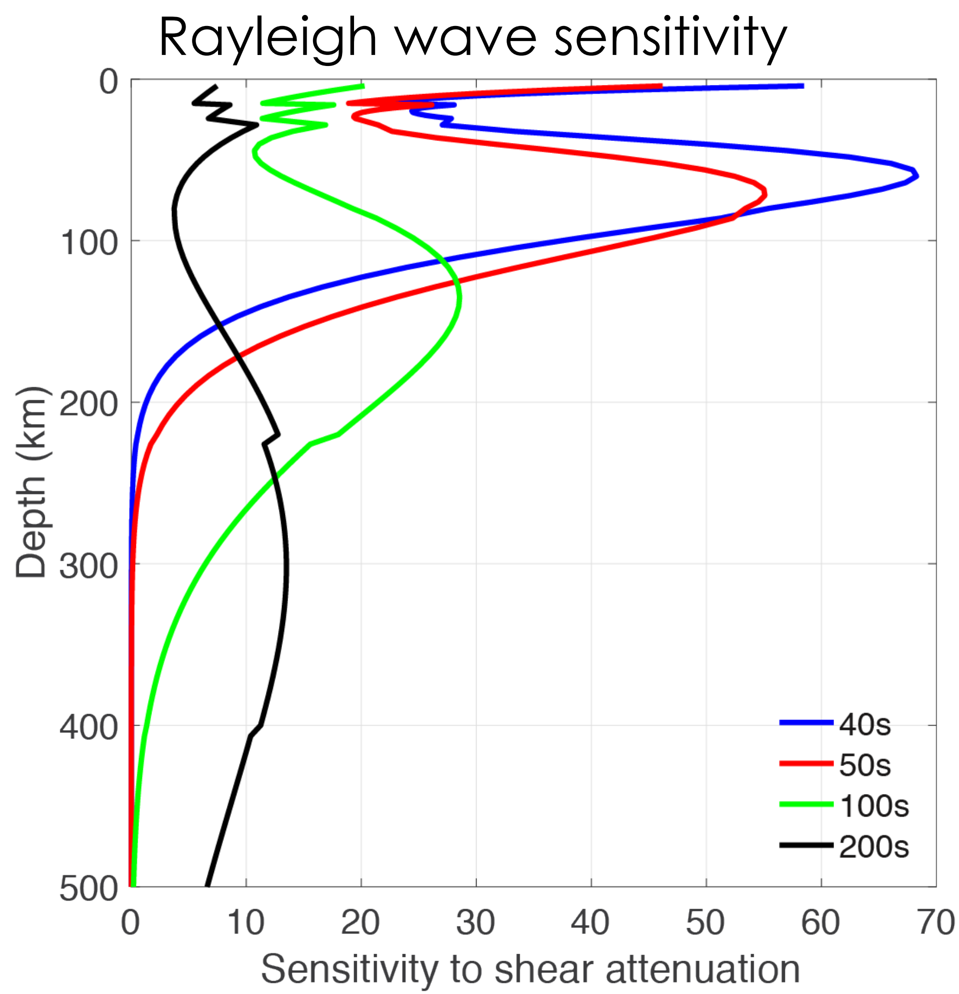
Effects of Composition



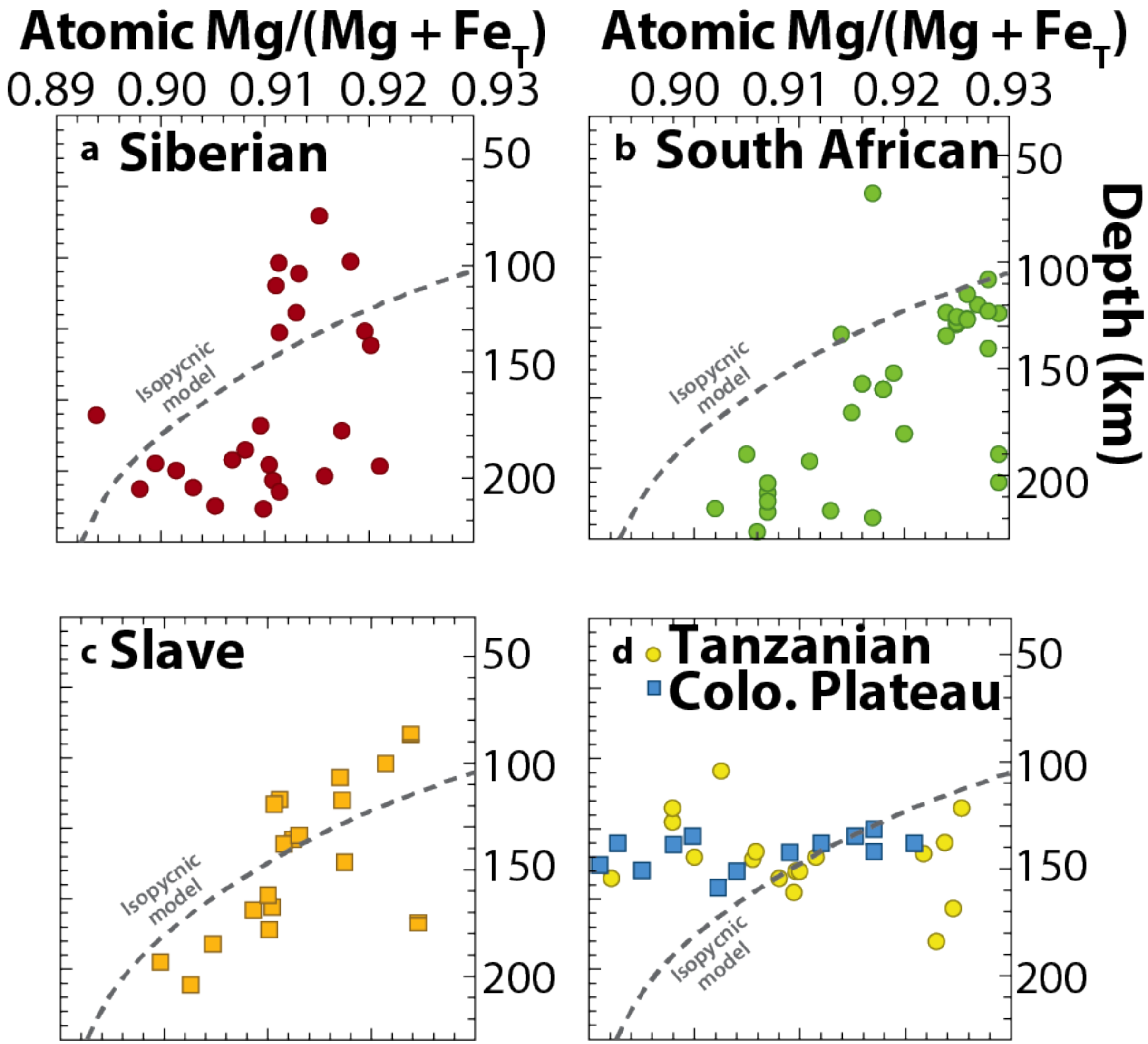

Depth (km)
100
150
200
250
300
350
4.2
4.4
4.6
4.8
5
Vs (km/s)

Surface-Wave Focusing and Sensitivity



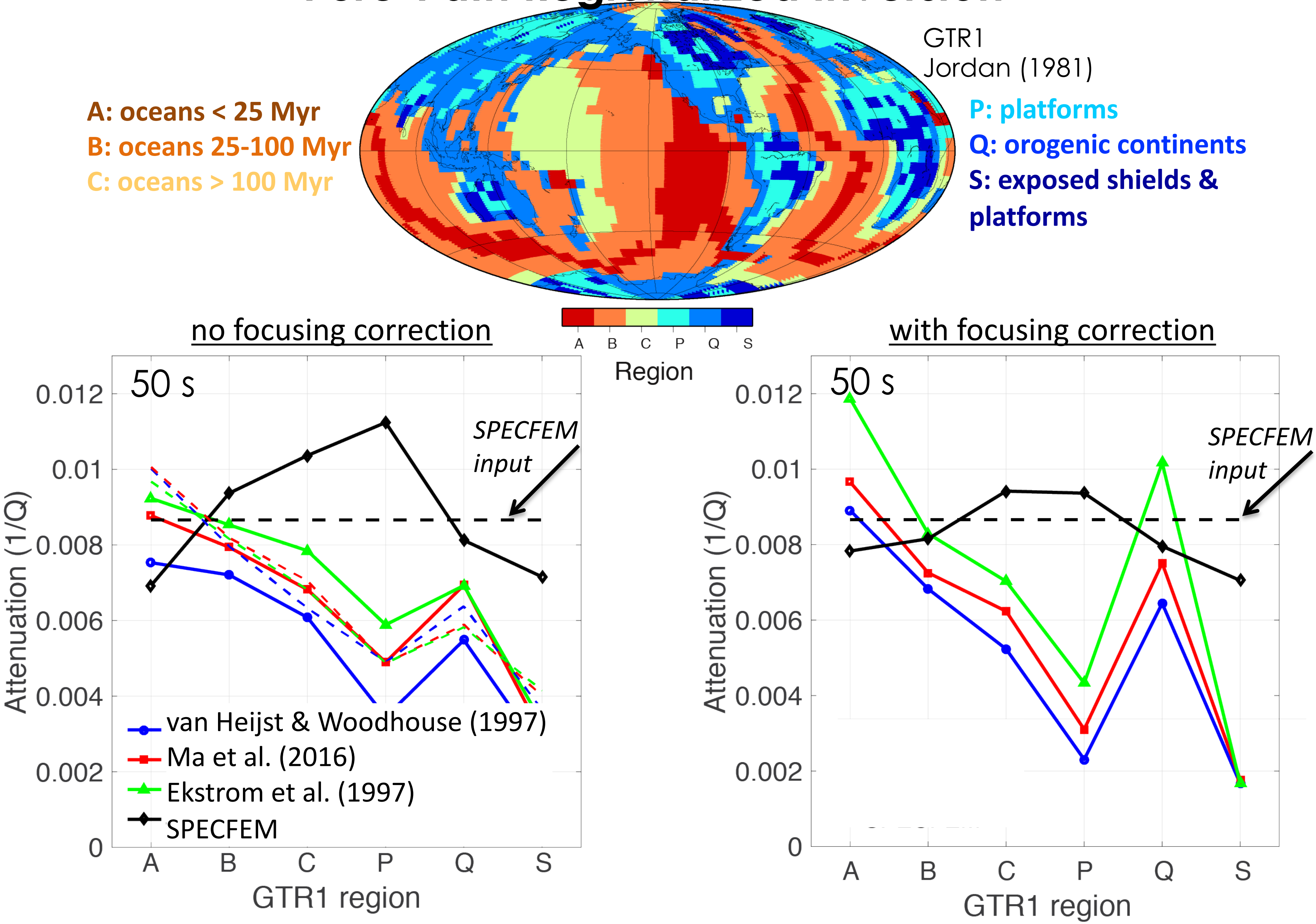


Effects of Composition

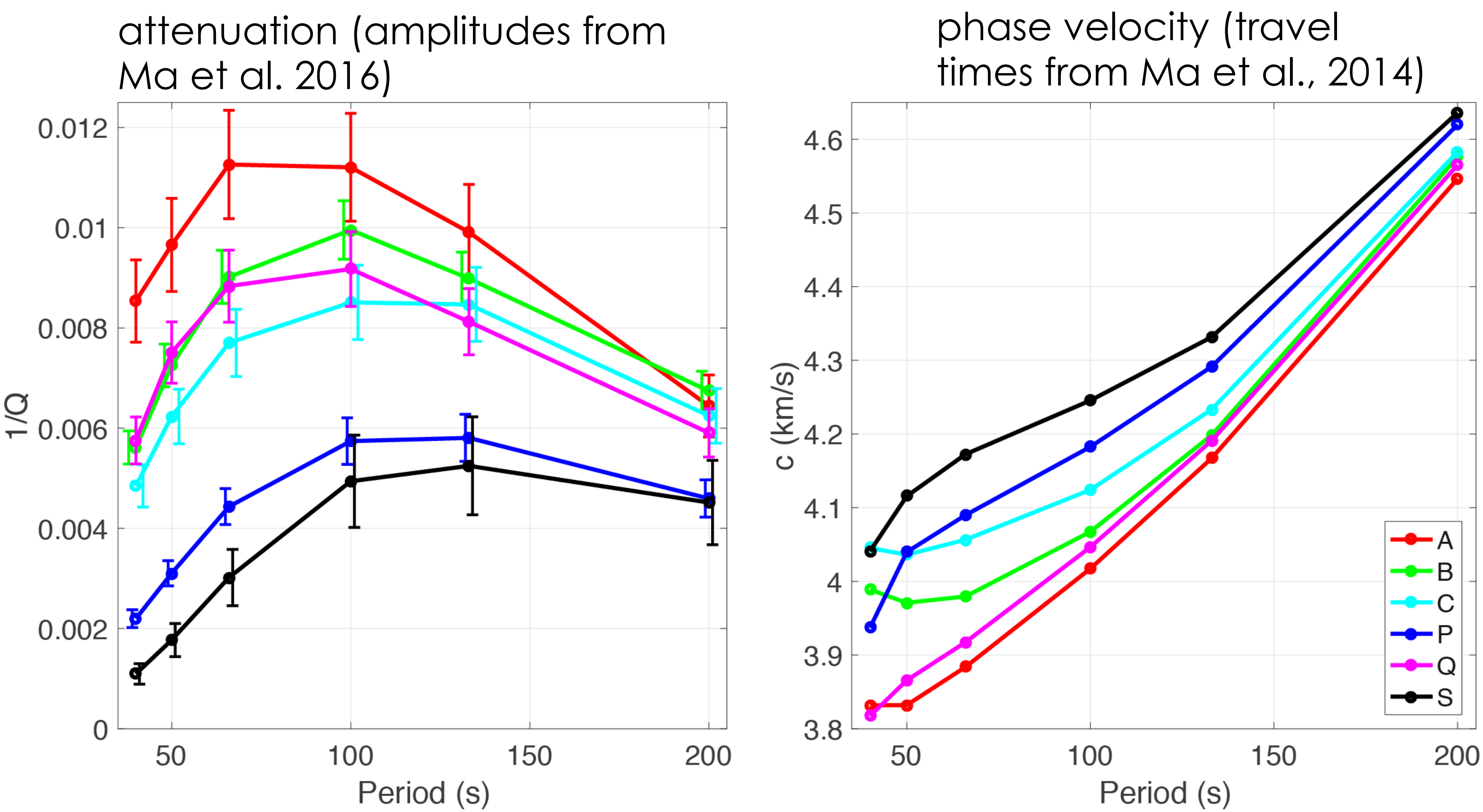


Lee et al. (2011)

Pure-Path Regionalized Inversion



Pure-Path Regionalized Inversion



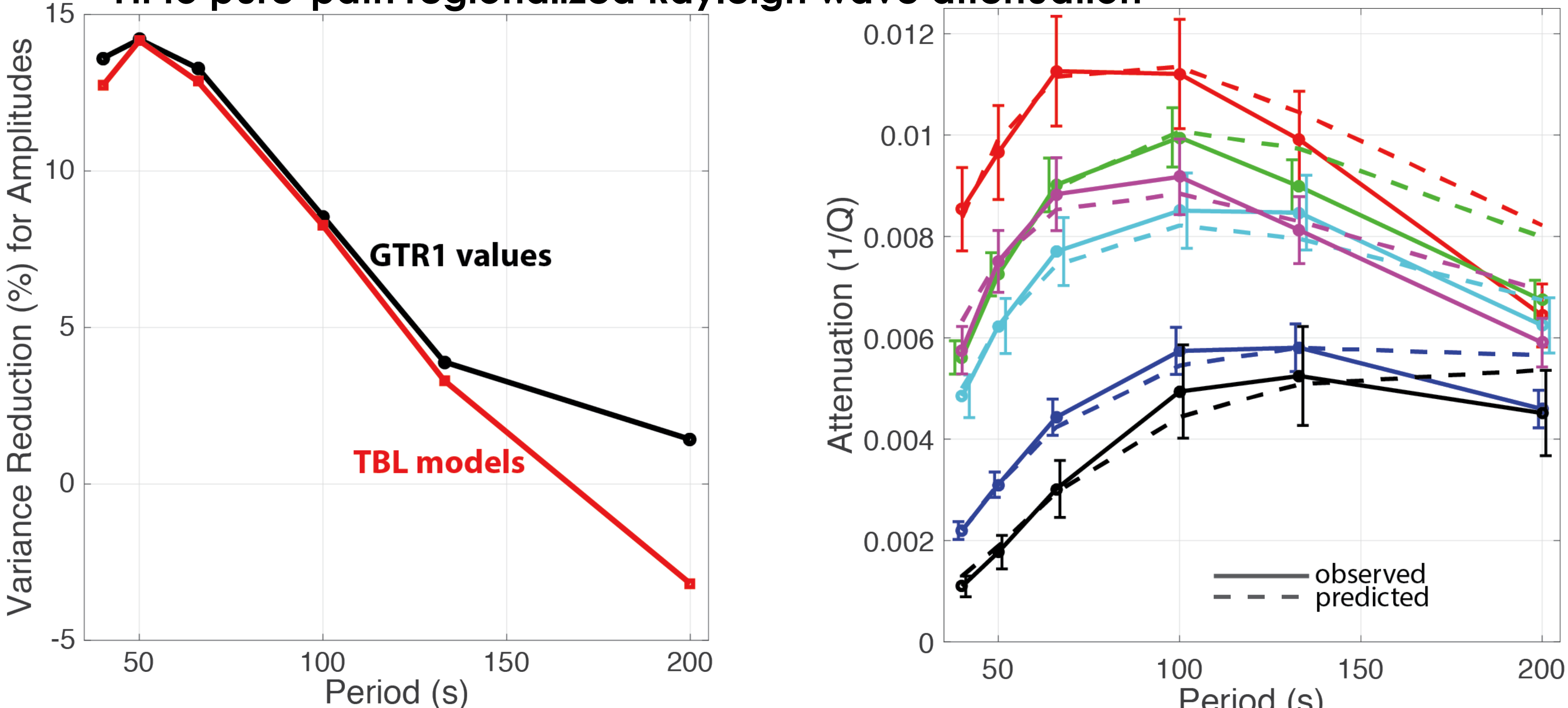
A: oceans < 25 Myr
B: oceans 25-100 Myr
C: oceans > 100 Myr
P: platforms
Q: orogenic continents
S: exposed shields & platforms

Dalton et al. (*EPSL*, 2017)

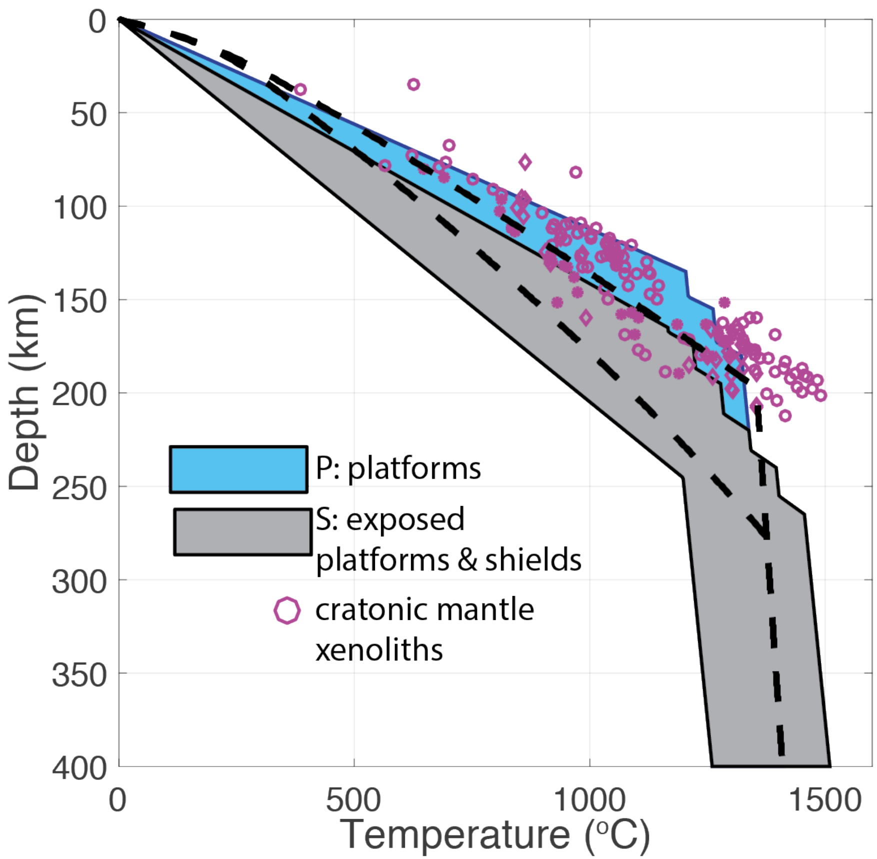
Thermal Structure

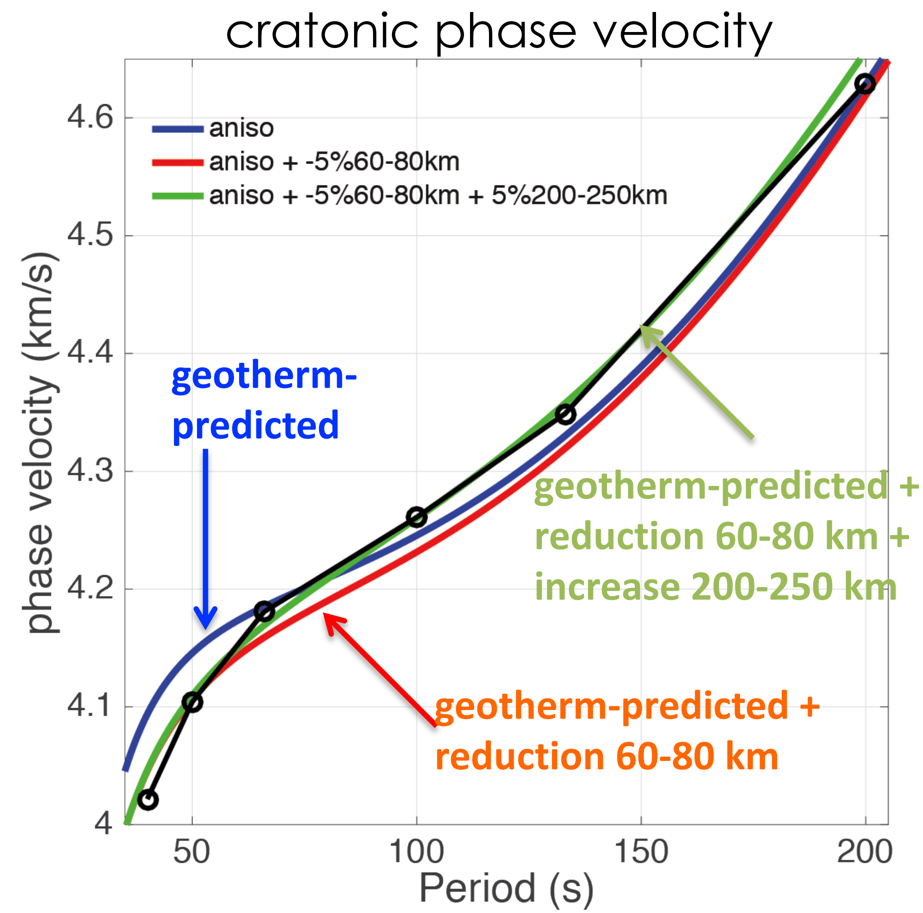
- Construct geotherms: vary potential temperature (T_P) of adiabat & layer thickness
- Convert temperature into shear attenuation and seismic velocity using Jackson and Faul (2010)
- Predict Rayleigh wave attenuation and phase velocity using Mineos

Fit to pure-path regionalized Rayleigh wave attenuation



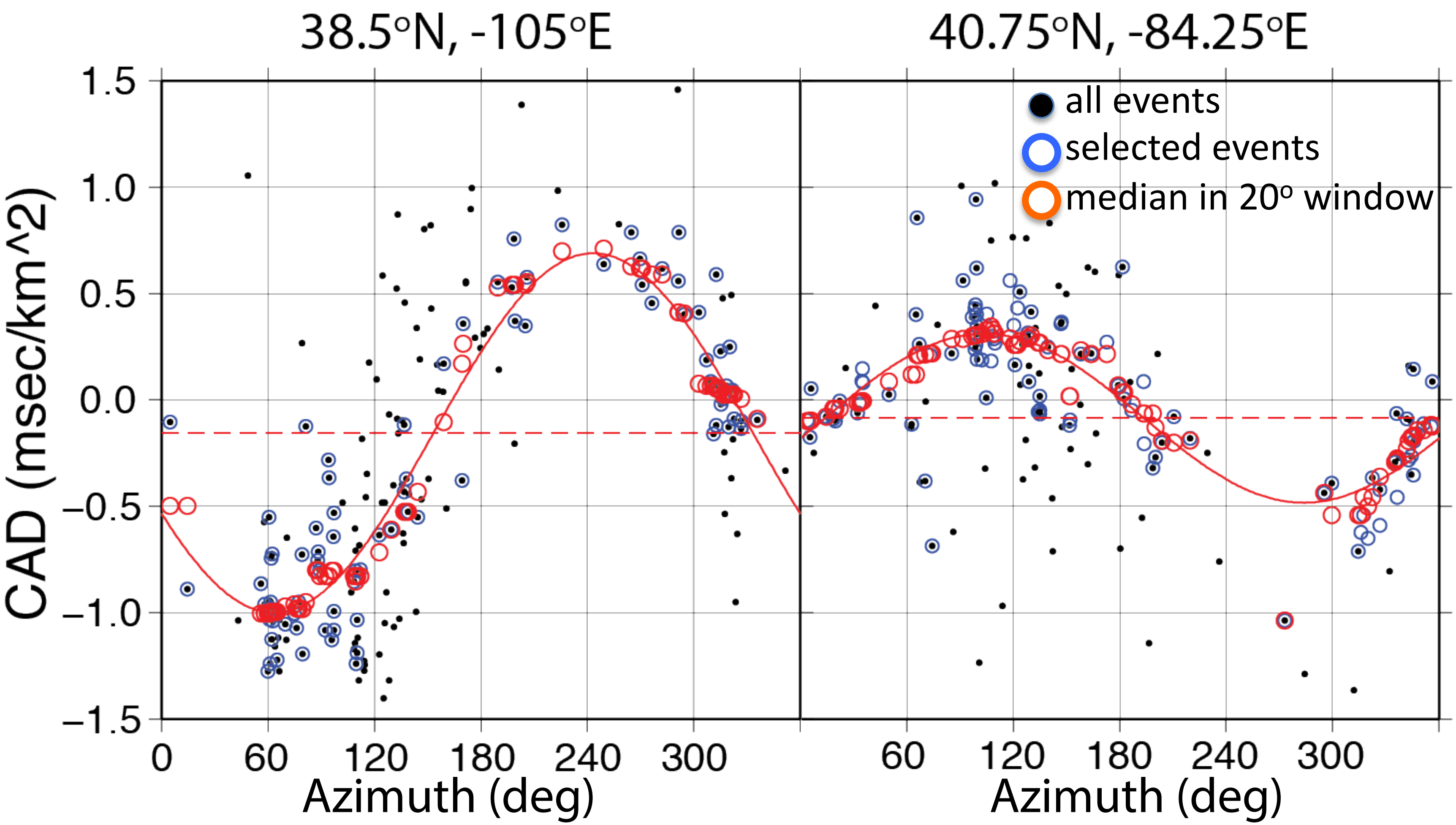
Thermal Structure





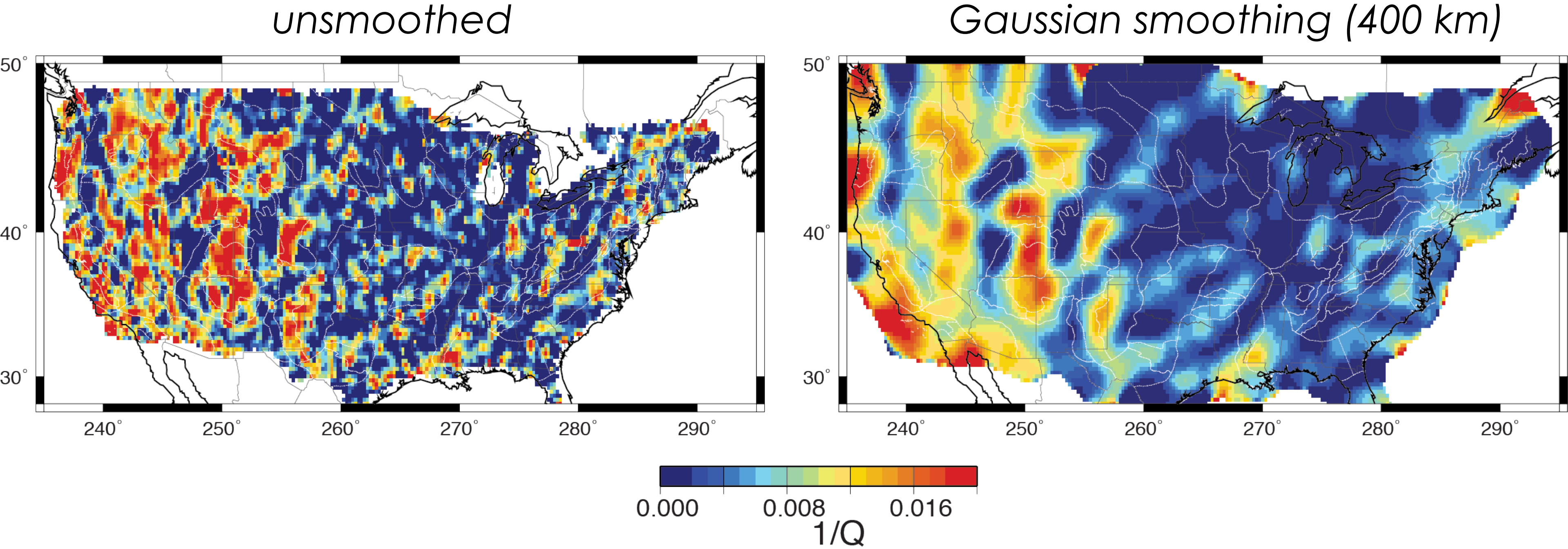
Curve-Fitting Approach

$$\frac{2\nabla\beta\cdot\nabla\tau}{\beta}-\frac{2\alpha}{c}=\frac{2\nabla A\cdot\nabla\tau}{A}+\nabla^2\tau \Rightarrow \frac{2}{c}\frac{\partial(\ln\beta)}{\partial x}\sin\theta+\frac{2}{c}\frac{\partial(\ln\beta)}{\partial y}\cos\theta-\frac{2}{c}\alpha=\underbrace{\frac{2\nabla A\cdot\nabla\tau}{A}+\nabla^2\tau}_{\text{CAD}}$$



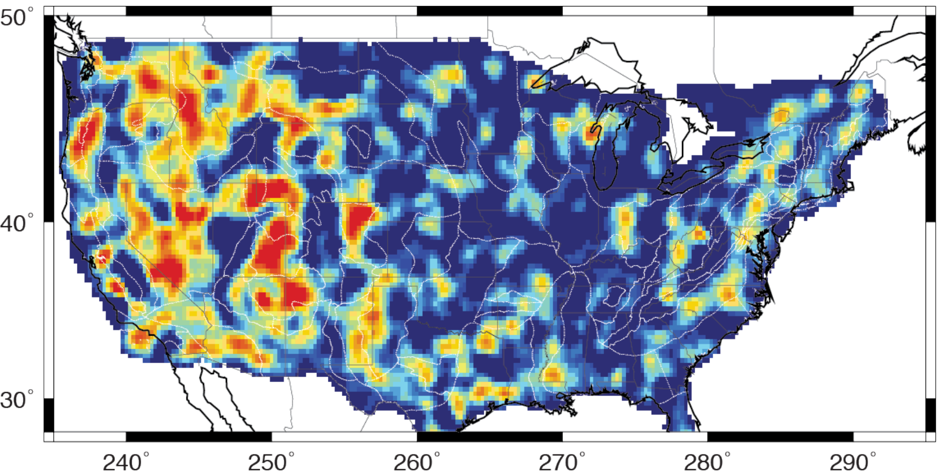
Curve-Fitting Approach

50-s Rayleigh waves

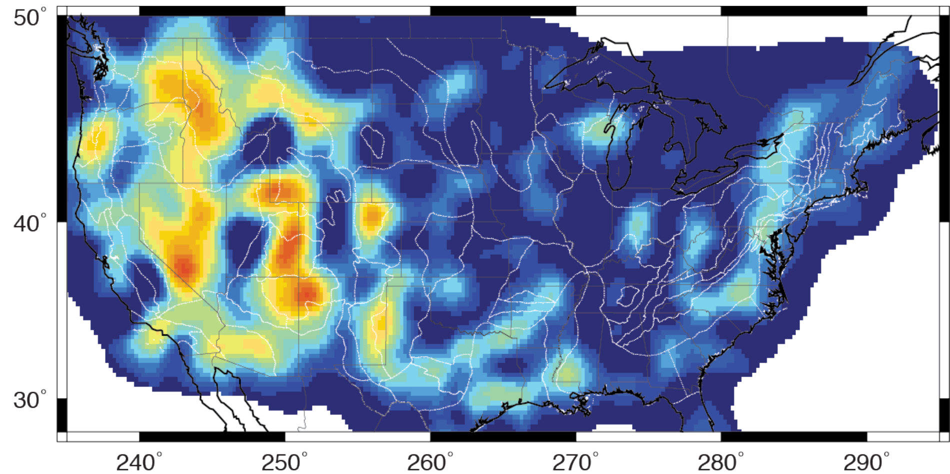


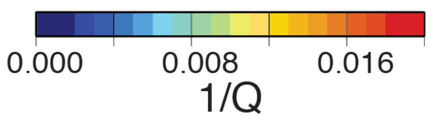
Azimuthal-Averaging Approach

unsmoothed

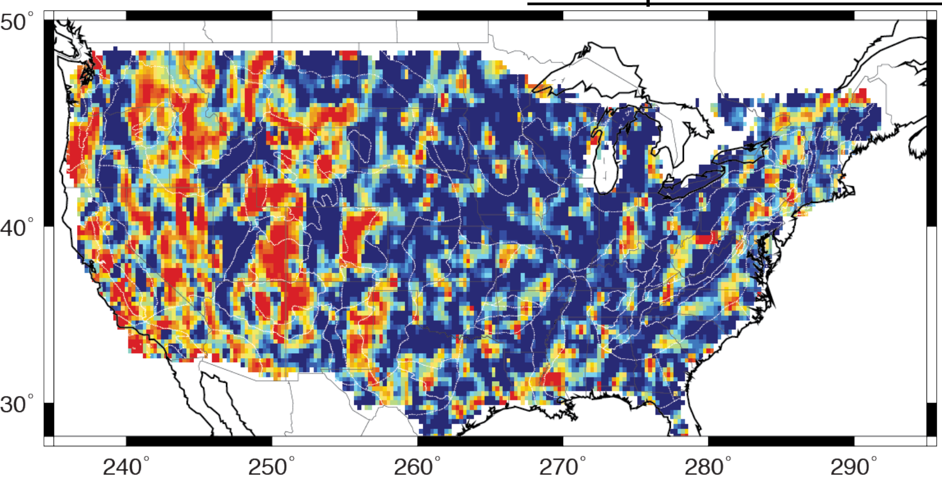


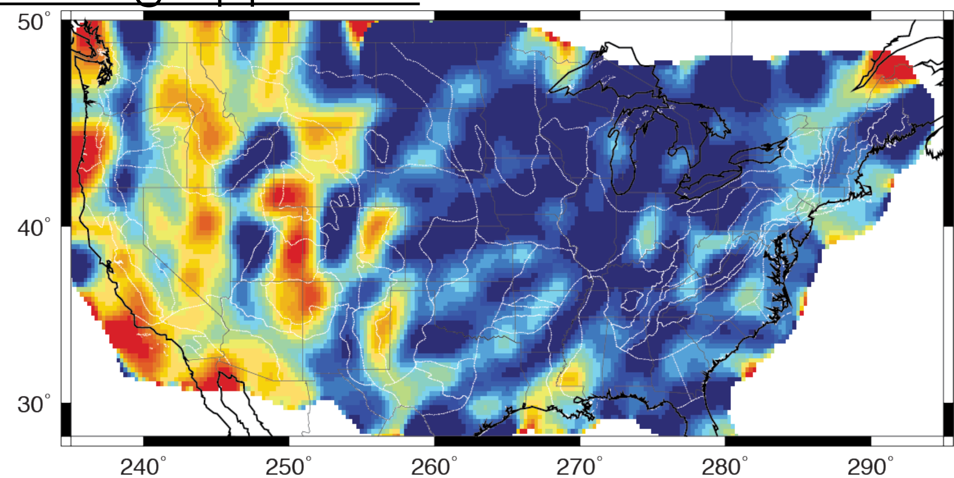
Gaussian smoothing (400 km)





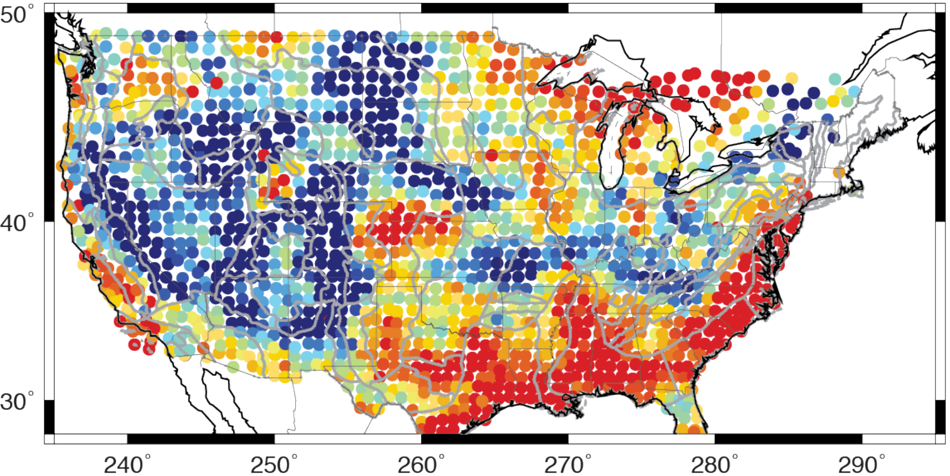
<u>Comparison: Curve-Fitting Approach</u>



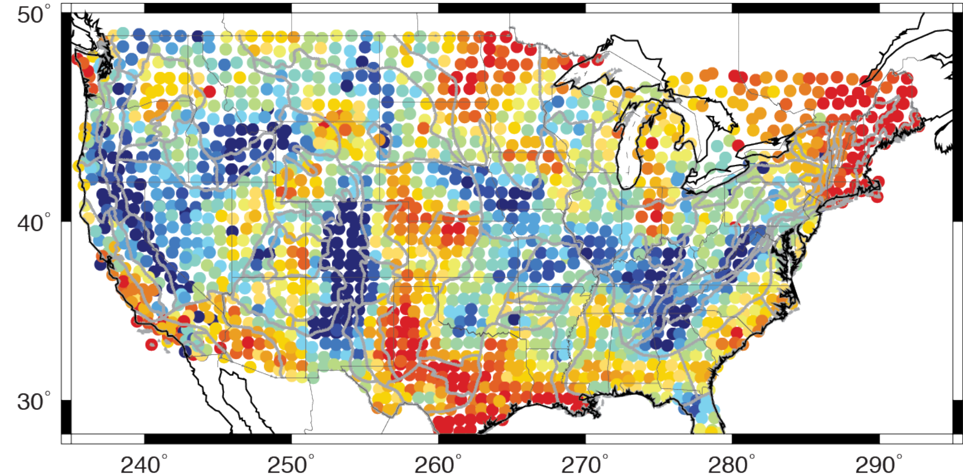


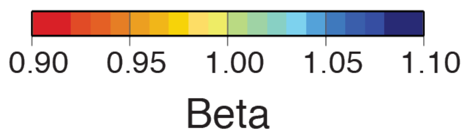
Independent Constraints on Local Site Amplification

amplitude ratio approach of Eddy and Ekström (2014)

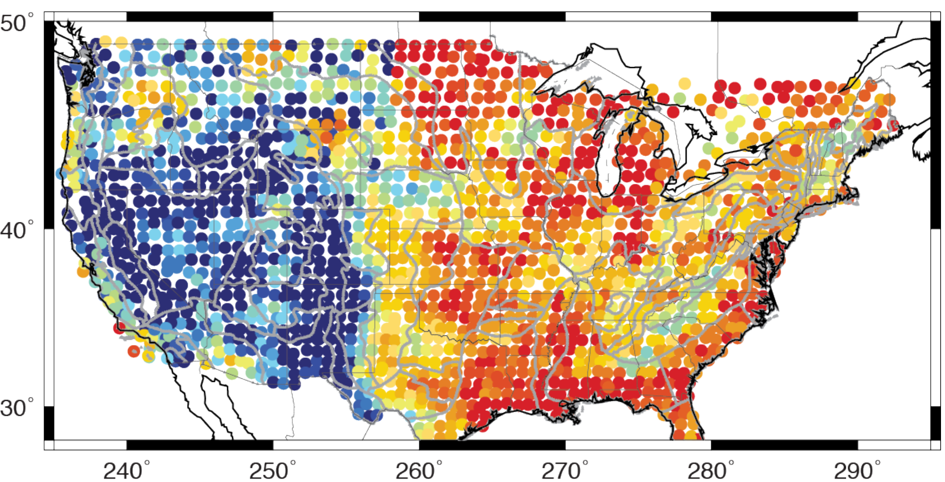


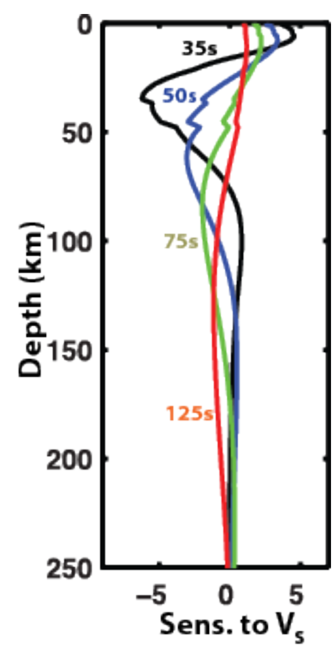
amplitude ratio approach applied to our data set





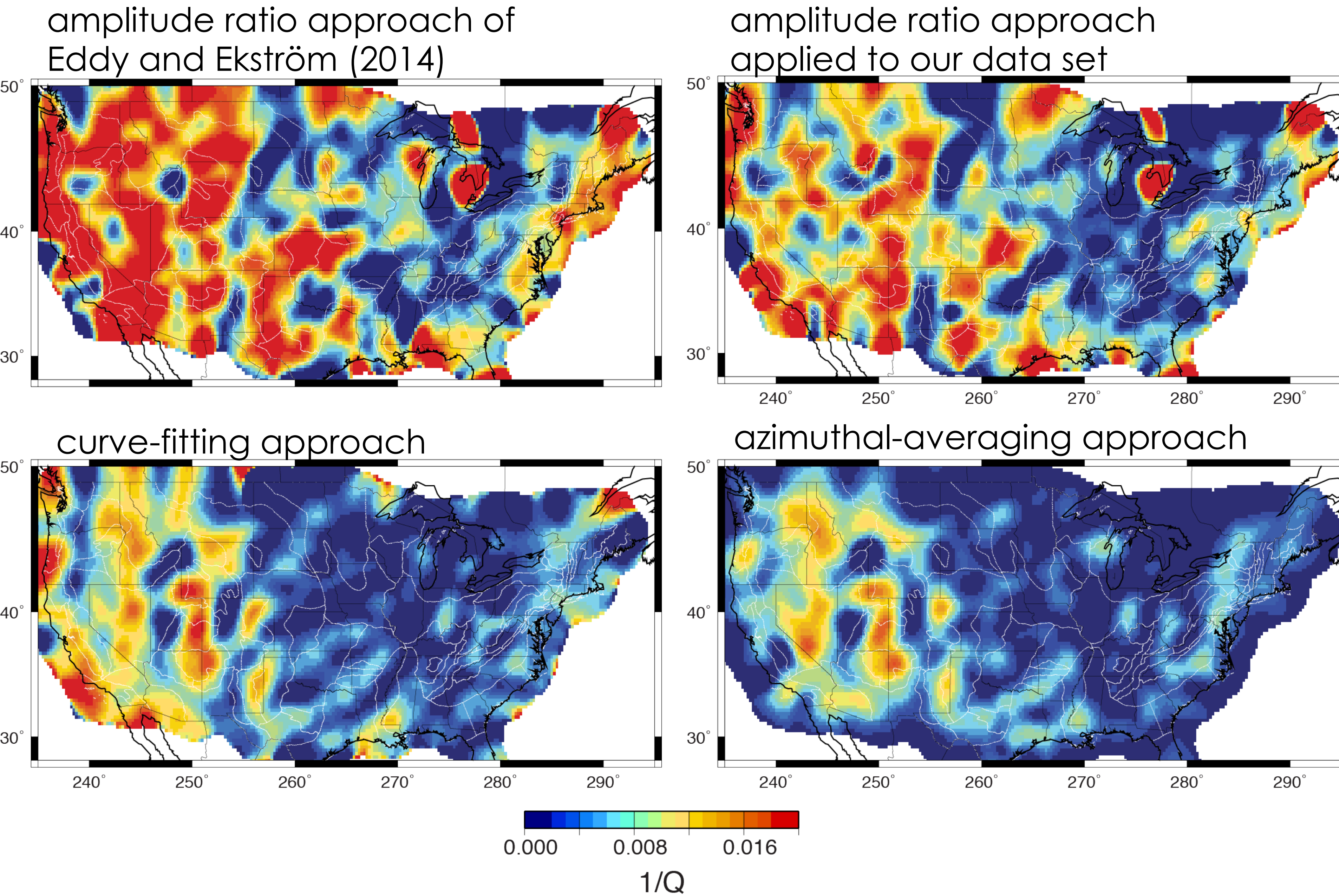
from curve-fitting approach



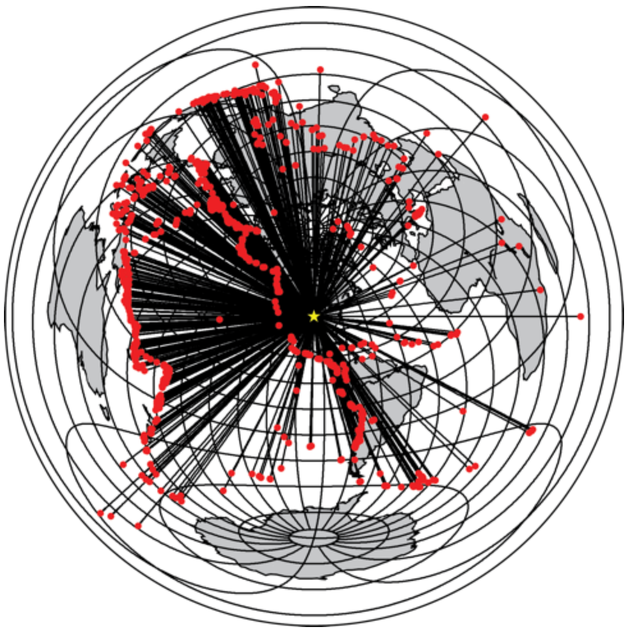


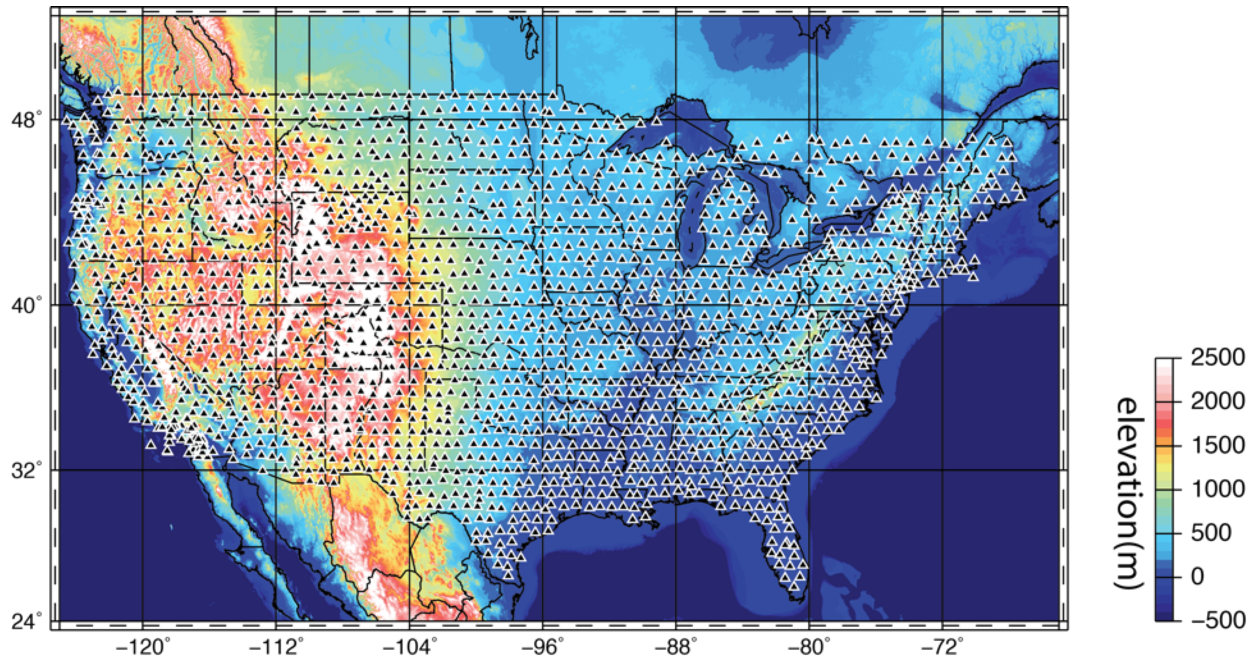
Eddy and Ekström (2014)

Independent Constraints on Local Site Amplification



Rayleigh Wave Phase & Amplitude





- 882 earthquakes from January 2, 2006 to March 3, 2015
- 1966 seismic stations

- travel time and amplitude measured using *Automated Surface Wave Phase Velocity Measuring System* (Jin & Gaherty, GJI, 2015)

- 389,552 Rayleigh waves measured

Helmholtz Equations

$$A_{ij}(\omega) = A_i^S(\omega)A_j^R(\omega)A_{ij}^F(\omega)A_{ij}^Q(\omega)$$

Use wavefront-tracking approach of Lin et al. (2012) to determine:

attenuation maps

$$\frac{2\nabla\beta\cdot\nabla\tau}{\beta} - \frac{2\alpha}{c} = \frac{2\nabla A\cdot\nabla\tau}{A} + \nabla^2\tau$$

receiver effects

attenuation

focusing effects

phase-velocity maps

$$\frac{1}{c^2} = \nabla\tau\cdot\nabla\tau - \frac{\nabla^2(A/\beta)}{\omega^2(A/\beta)}$$

<u>observations</u>
τ= travel times
A = amplitudes

<u>unknowns</u>
c = phase velocity
a = attenuation coeff.
= ω / 2UQ
β = site amplification