Global Rayleigh wave phase velocity maps from finite-frequency tomography

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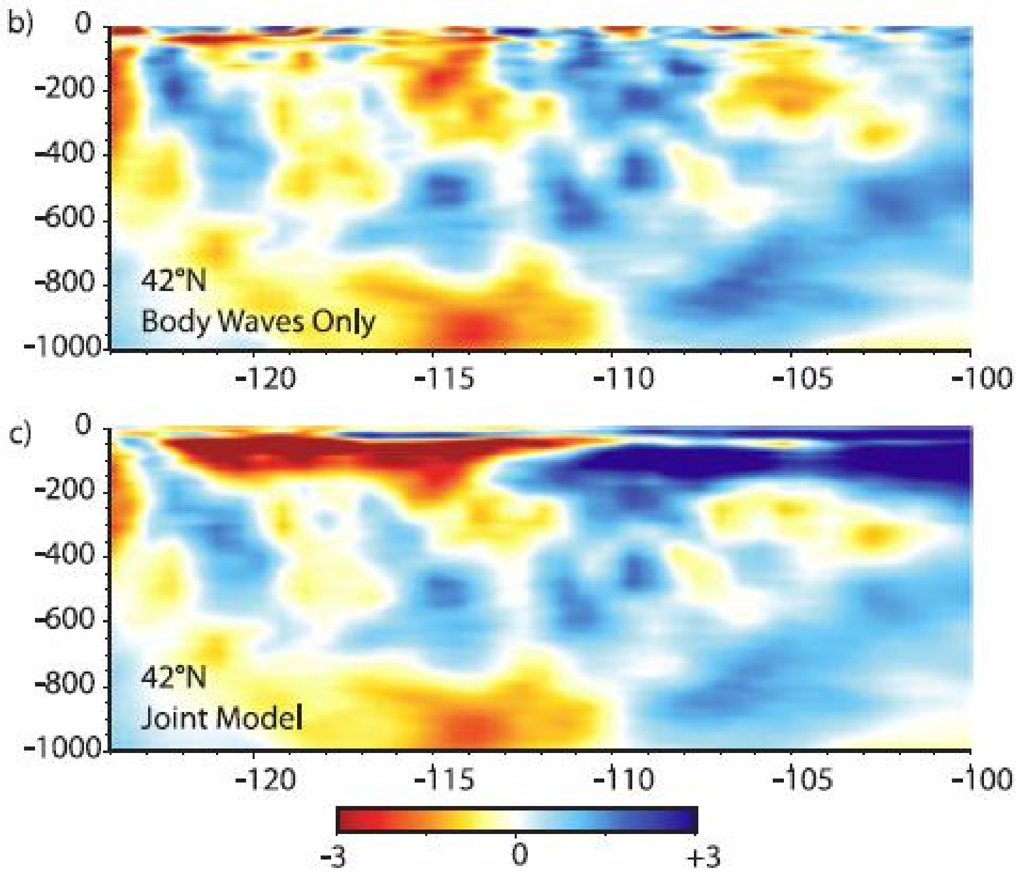
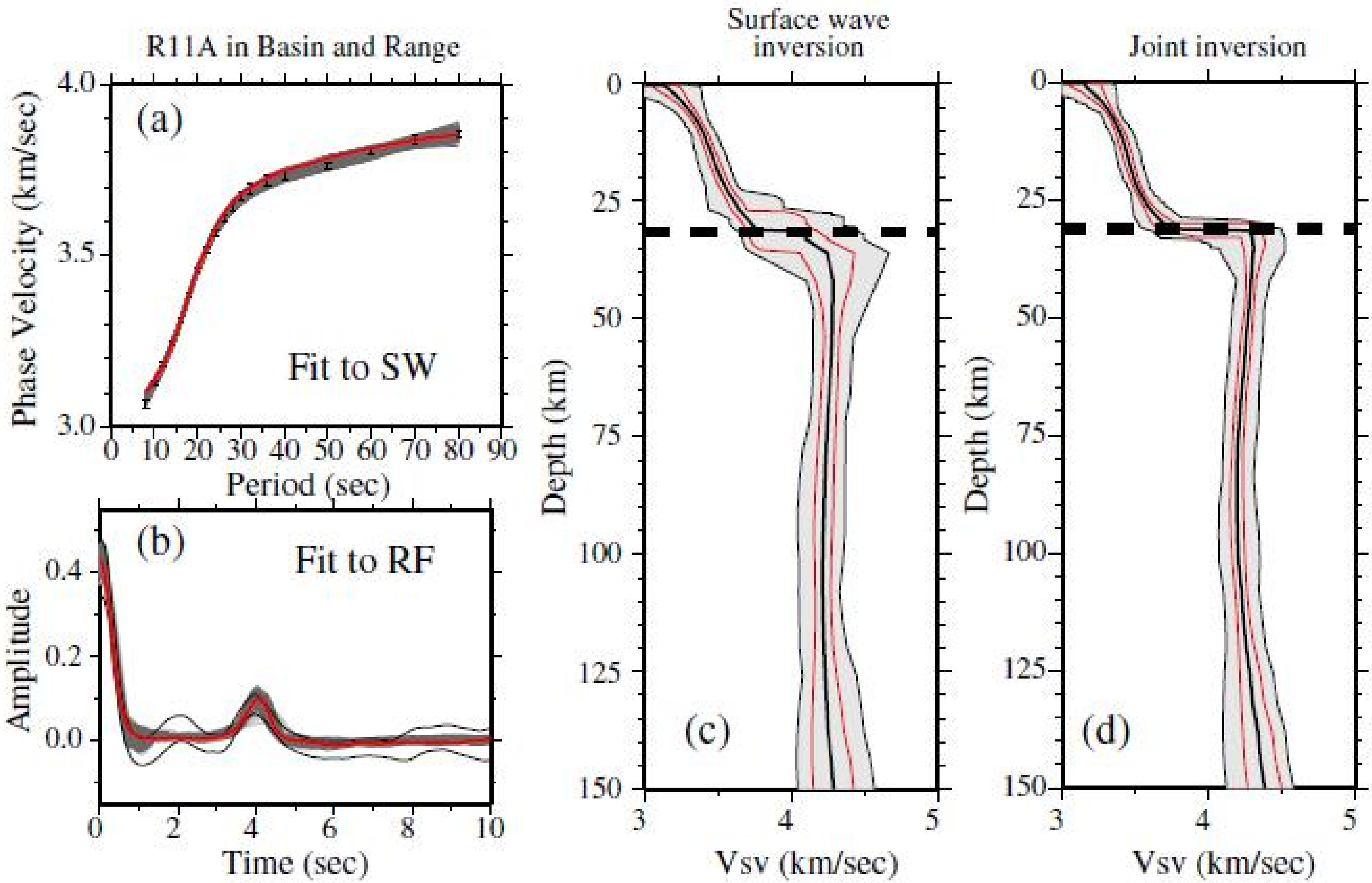
Yunnan University

Incorporation with Dr. Ying Zhou

Including surface phase velocity data improves the resolution in the upper mantle

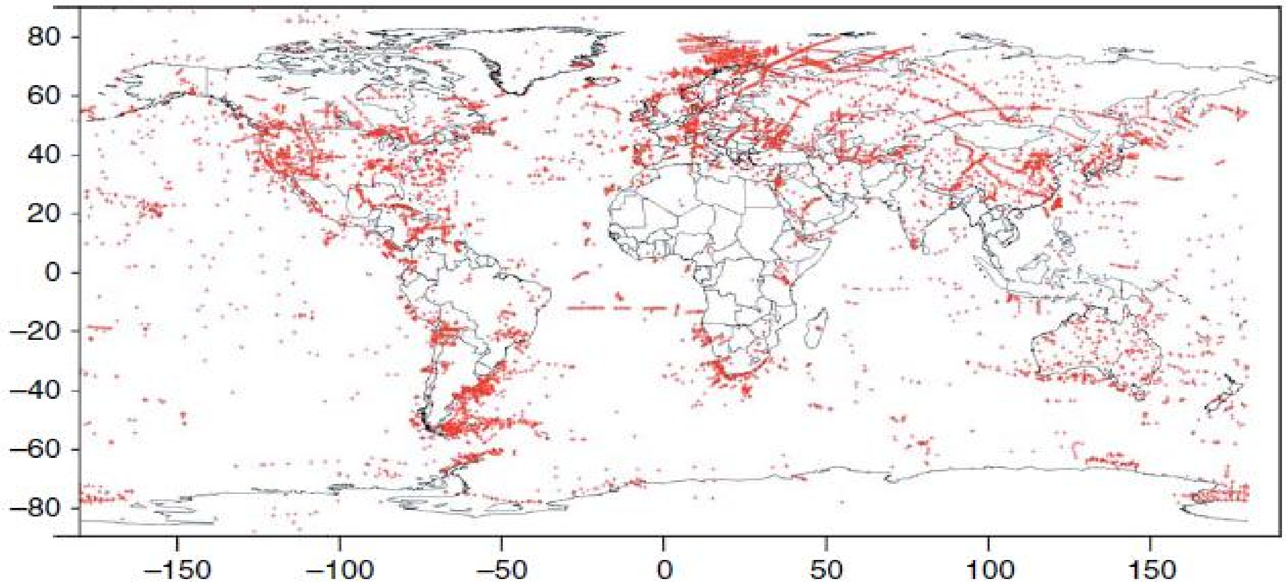


Obrebski et al. ,2011

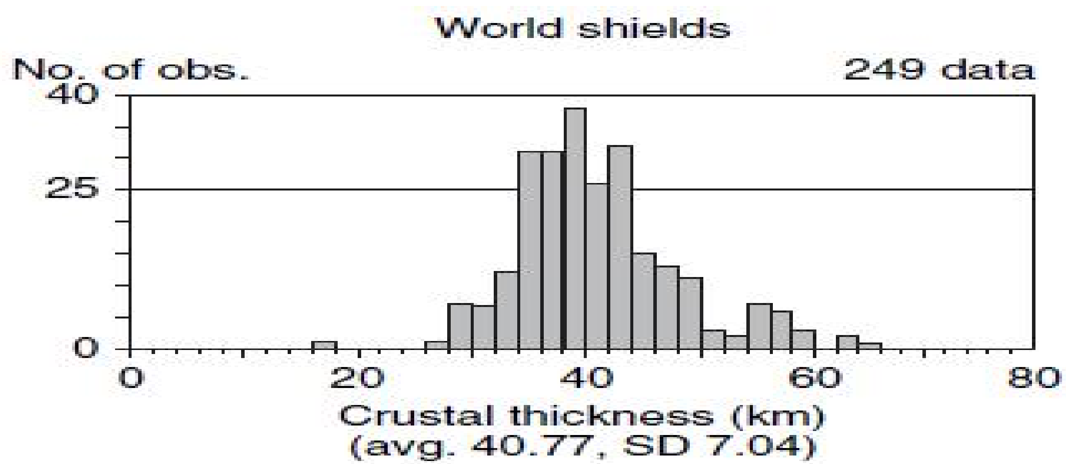


Shen et al. 2013

Data coverage of model CRUST2.0



In places with no data: using global averages

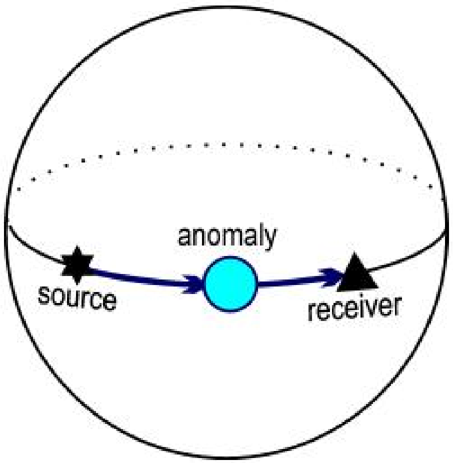


Mooney 2007

Surface wave data can also be used

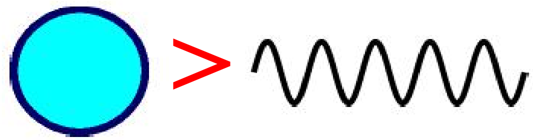
- to double check the noise measurments ;
- in joint inversion with SKS splitting measurements (e.g. Yuan and Romanowicz, 2010).

Wave diffraction

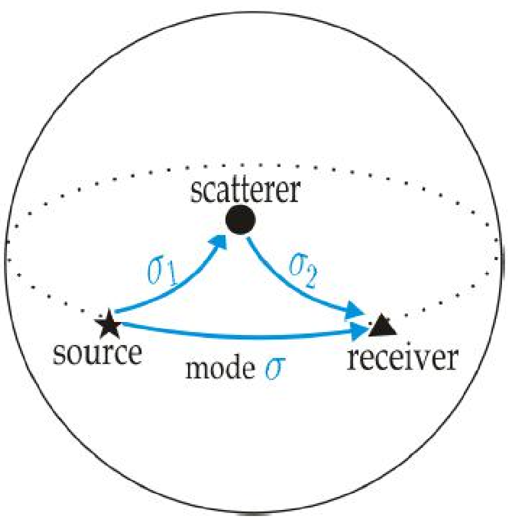


Ray theory:

(1) Valid if anomaly size > wavelength



(2) Breaks down if anomaly size~ wavelength



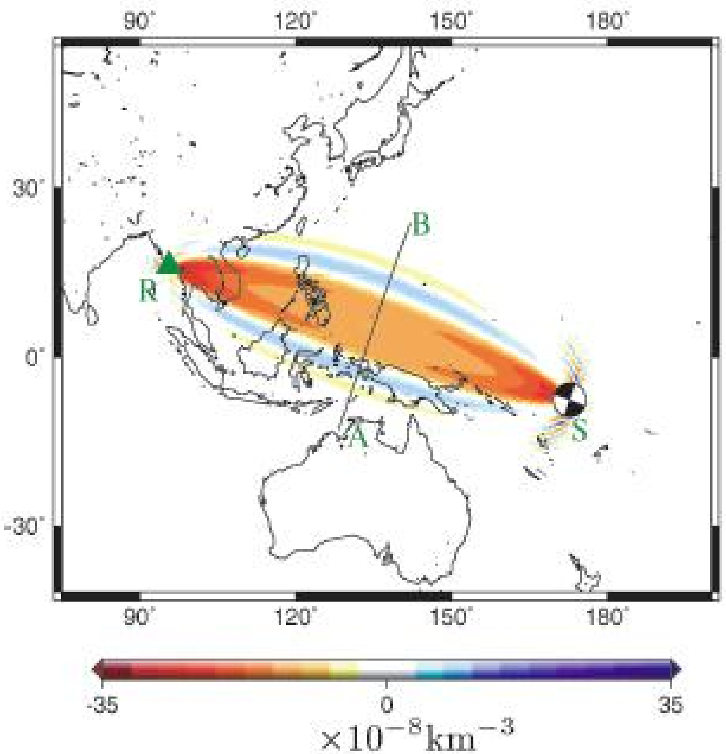
Finite-frequency theory:

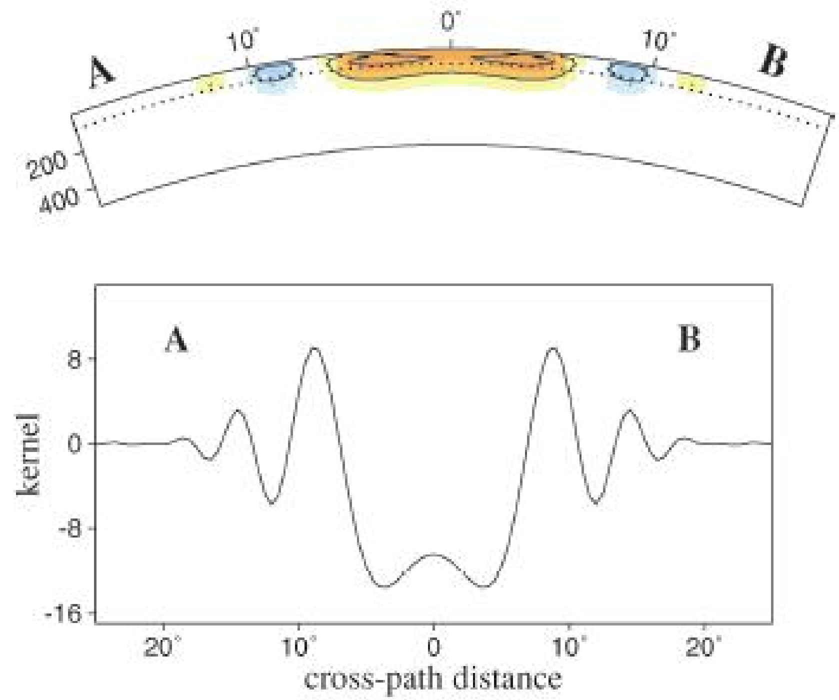
Account for diffractions by scatterers

$$\delta\phi(\omega) = \iiint_{\oplus} K_\beta(\omega, \mathbf{x})\, \frac{\delta\beta}{\beta}(\mathbf{x})\, d^3\mathbf{x}, \quad \text{Love waves}$$

$$\delta\phi(\omega) = \iiint_{\oplus} \left[K_\beta(\omega, \mathbf{x})\, \frac{\delta\beta}{\beta}(\mathbf{x}) + K_\alpha(\omega, \mathbf{x})\, \frac{\delta\alpha}{\alpha}(\mathbf{x}) \right] d^3\mathbf{x},$$

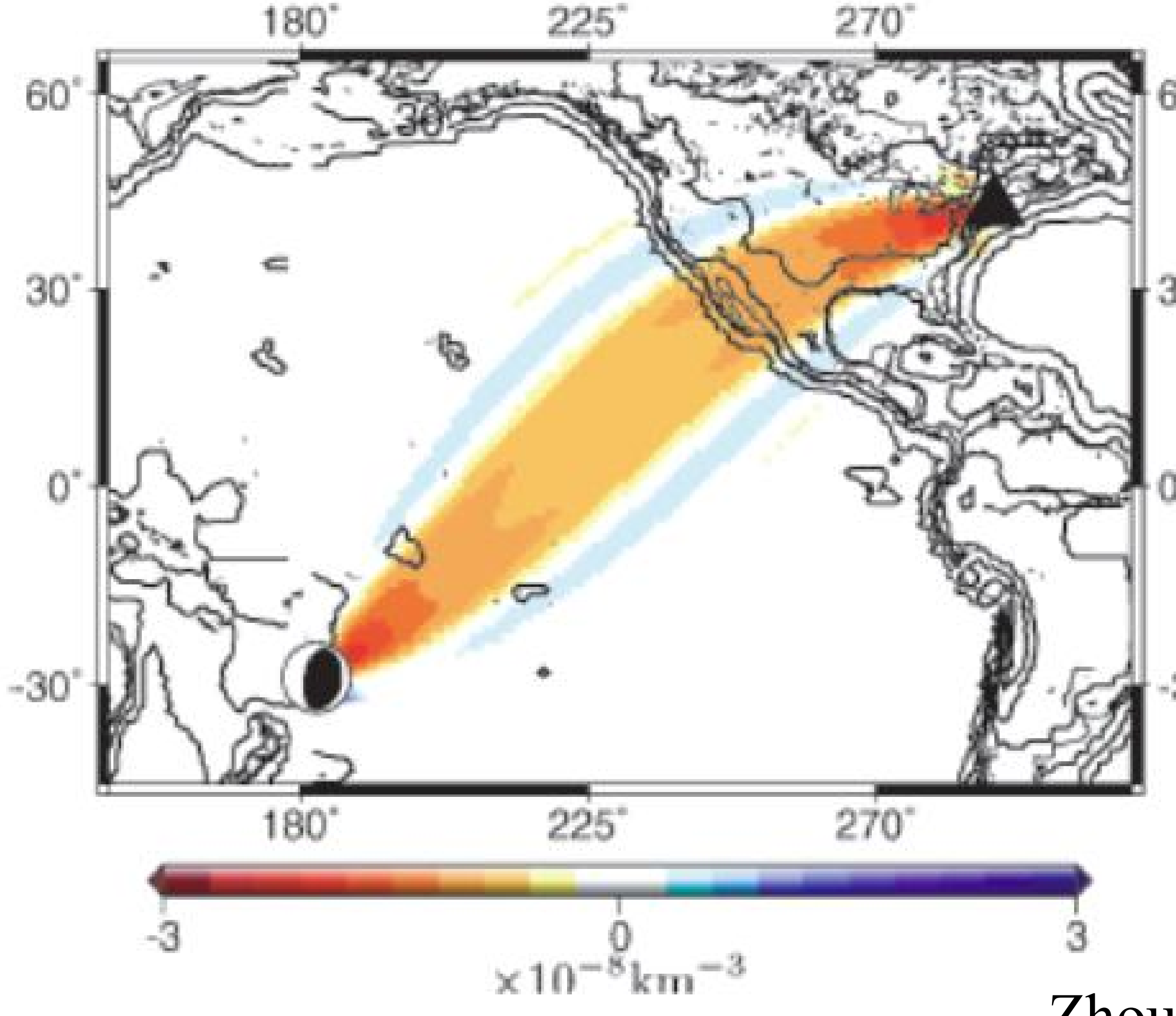
Rayleigh waves,



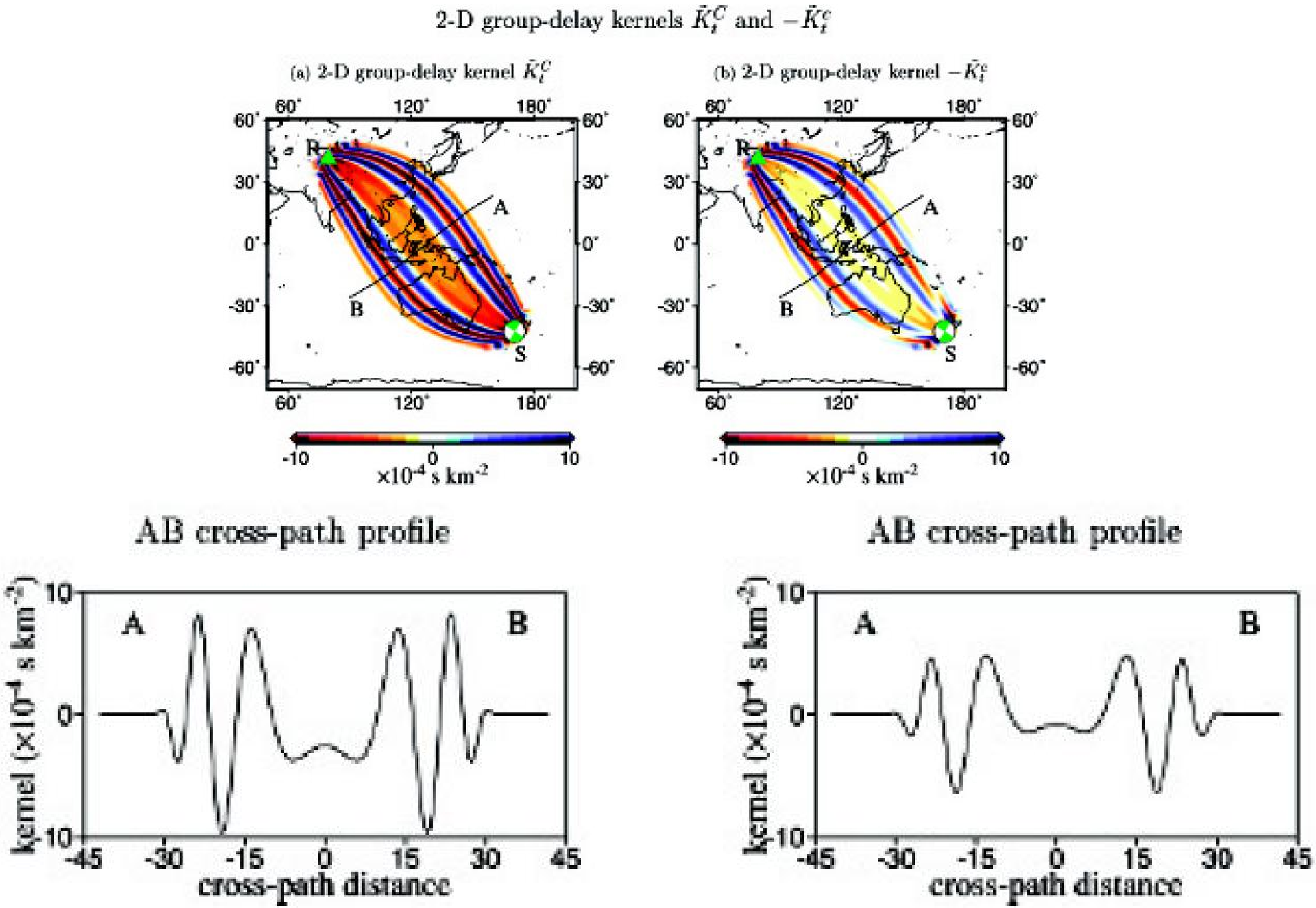


Zhou et al. ,2005

$$\delta\phi = \iint_{\Sigma} K_d \, \delta d \; d\Sigma,$$

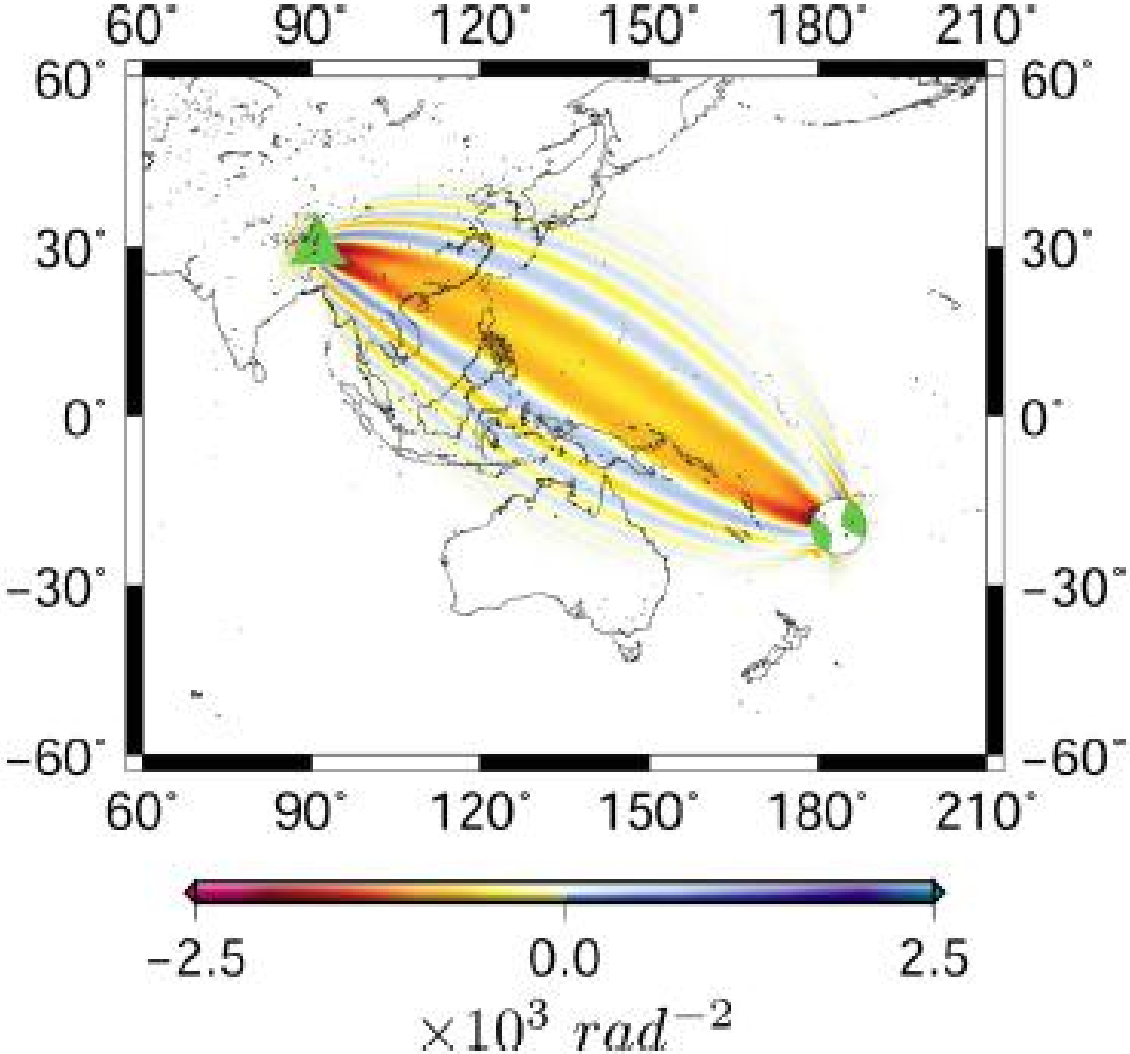


Zhou et al. ,2005



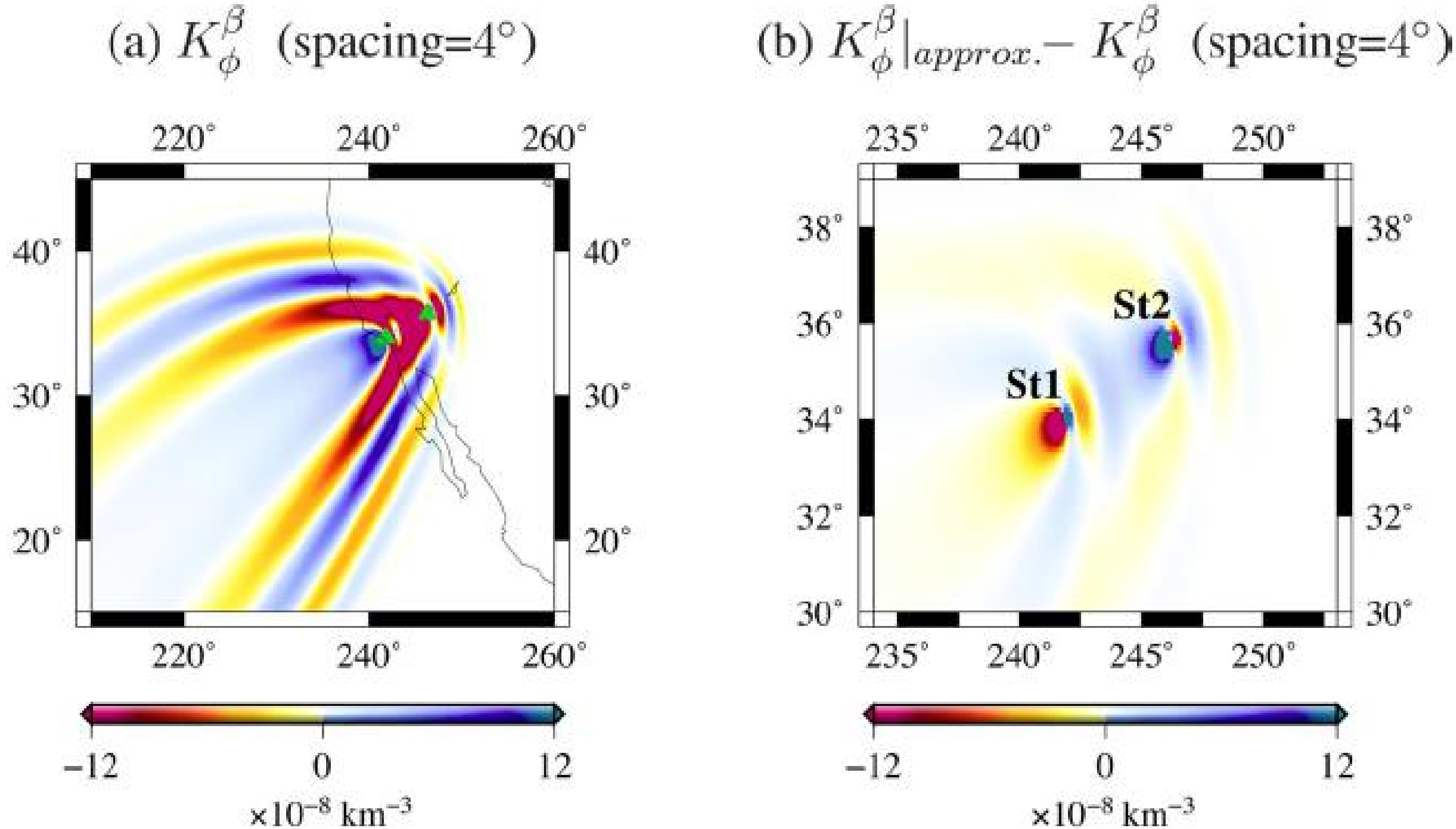
Dahlen and Zhou, 2006

2-D phase-velocity kernels



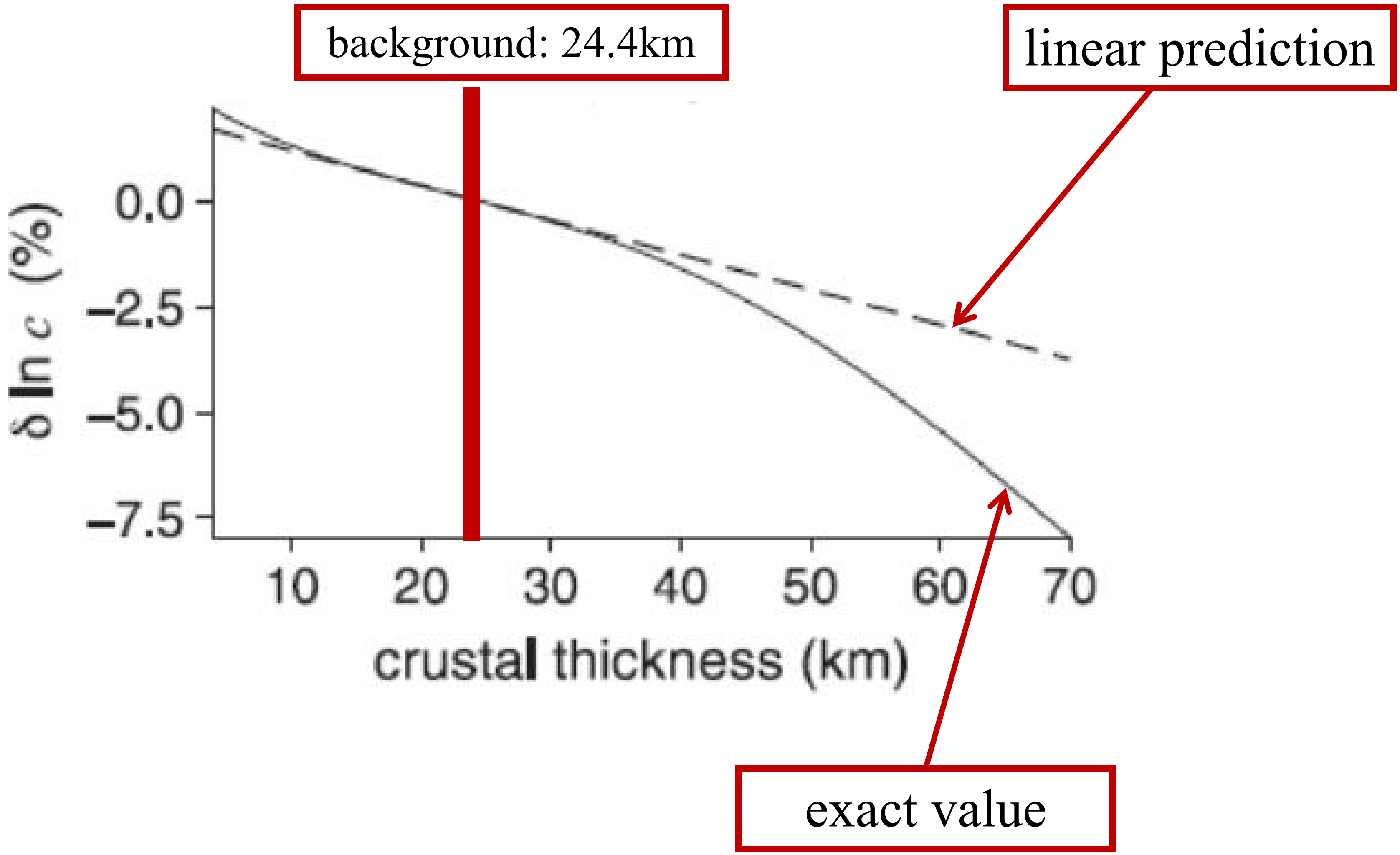
Liu and Zhou 2013

kernel for interstation measurements



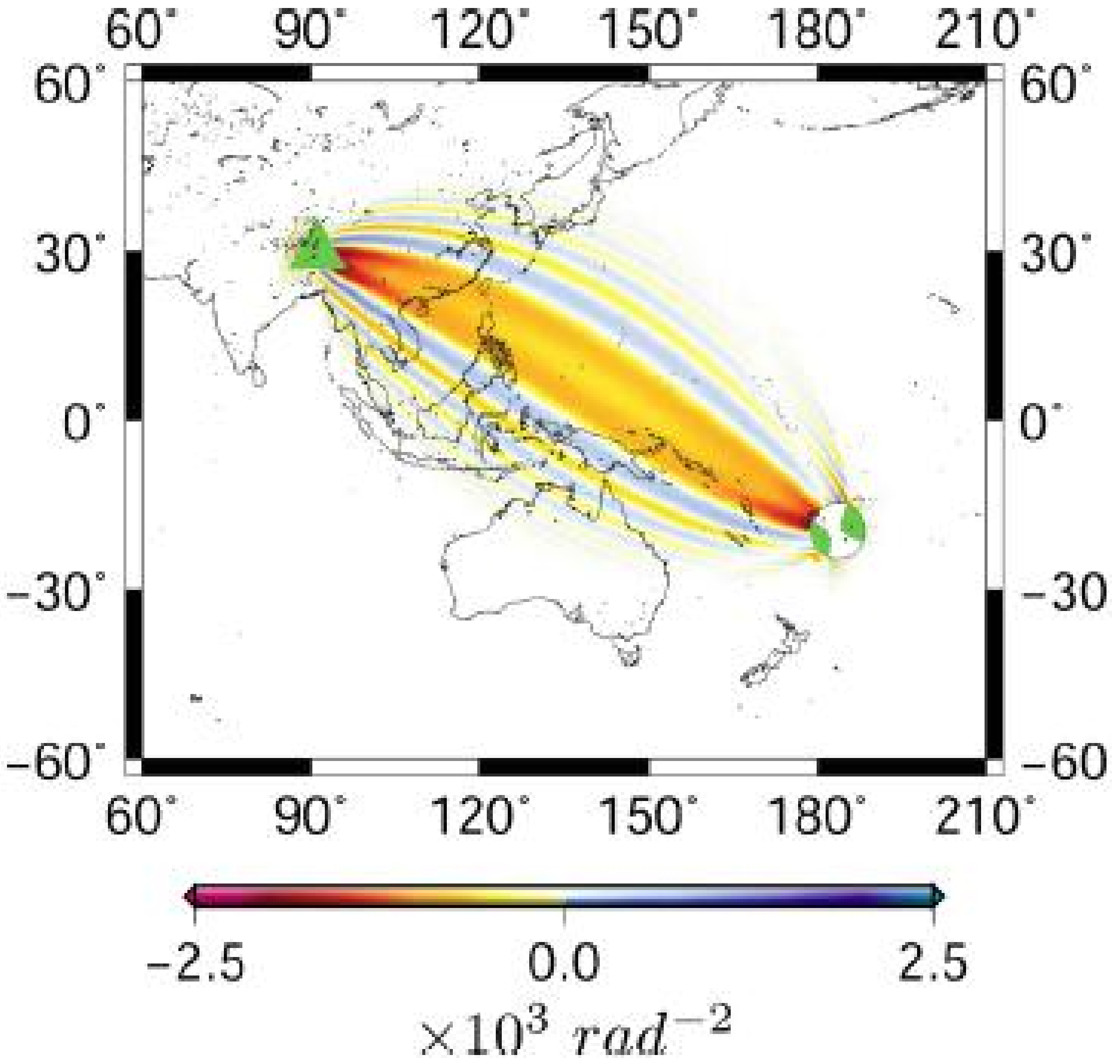
Liu and Zhou, 2016

Crustal effects on surface waves---*nonlinearity*



Liu and Zhou, 2013

2-D phase-velocity kernels

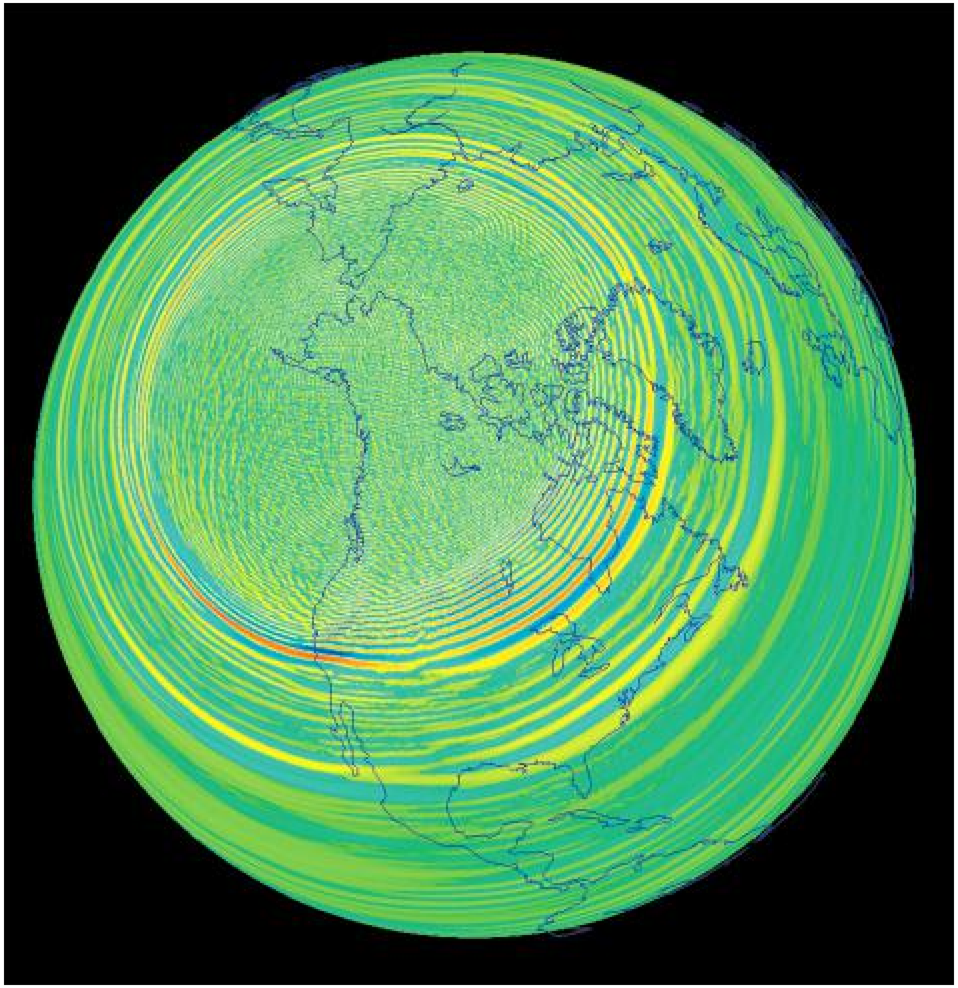


Liu and Zhou 2013

Using SEM to simulate wave propagation

cluster

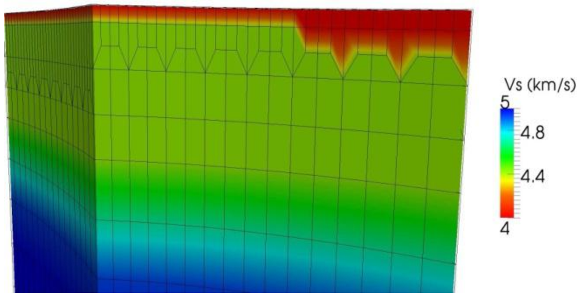
Snapshot of wave propagation



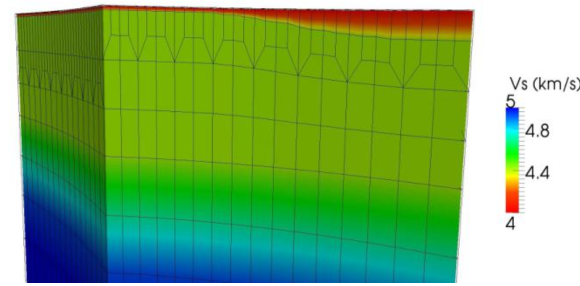
Komatitsch et al. 2008

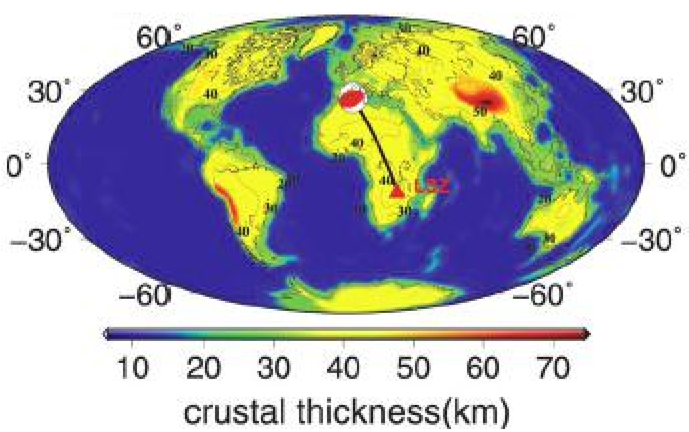
Using SEM to simulate wave propagation

run-through mesh

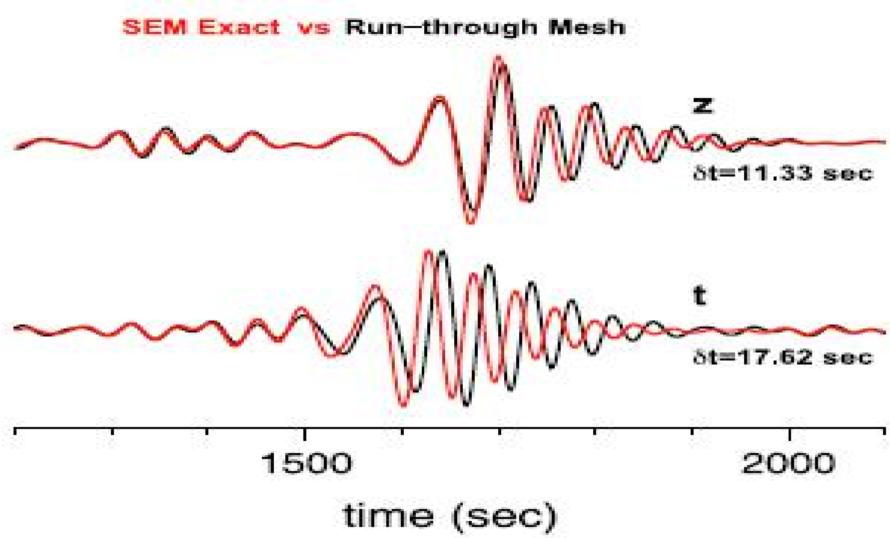


exact mesh



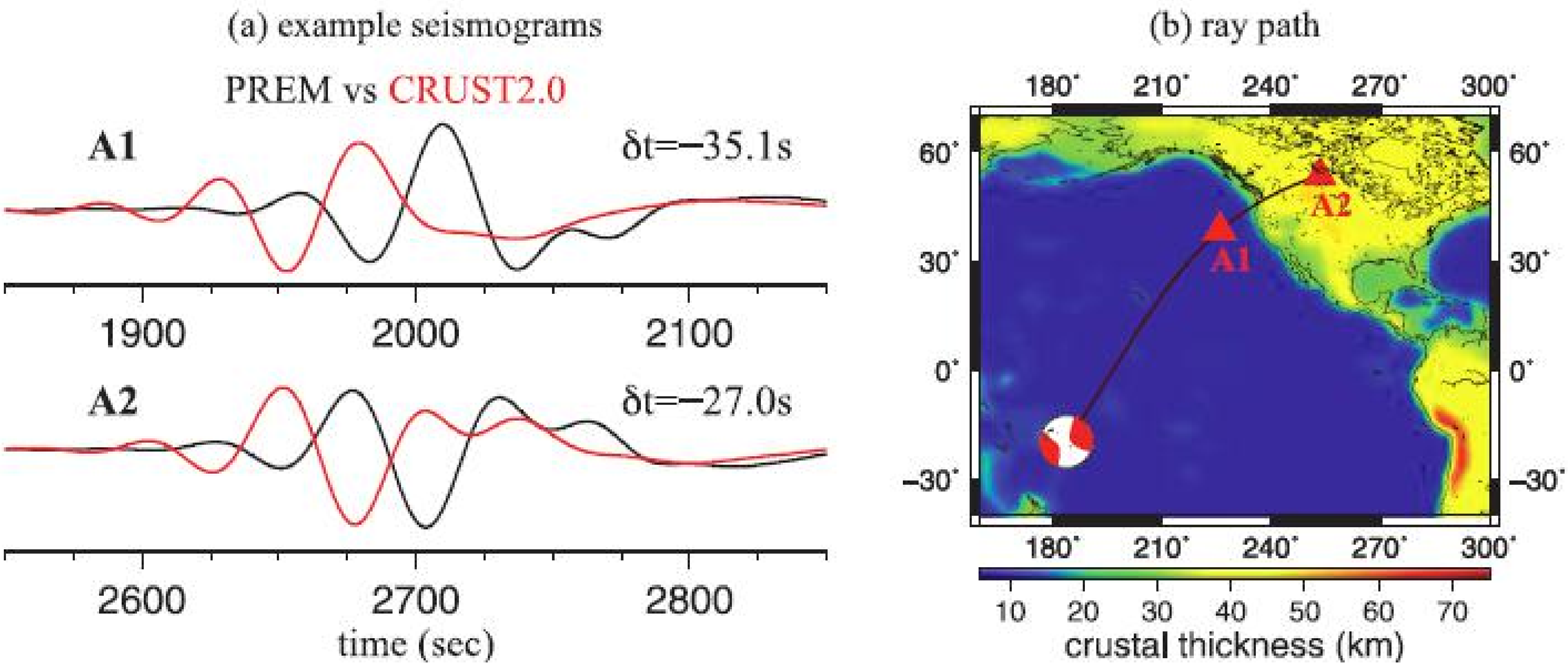


Seismograms for two meshes



Liu and Zhou, 2013

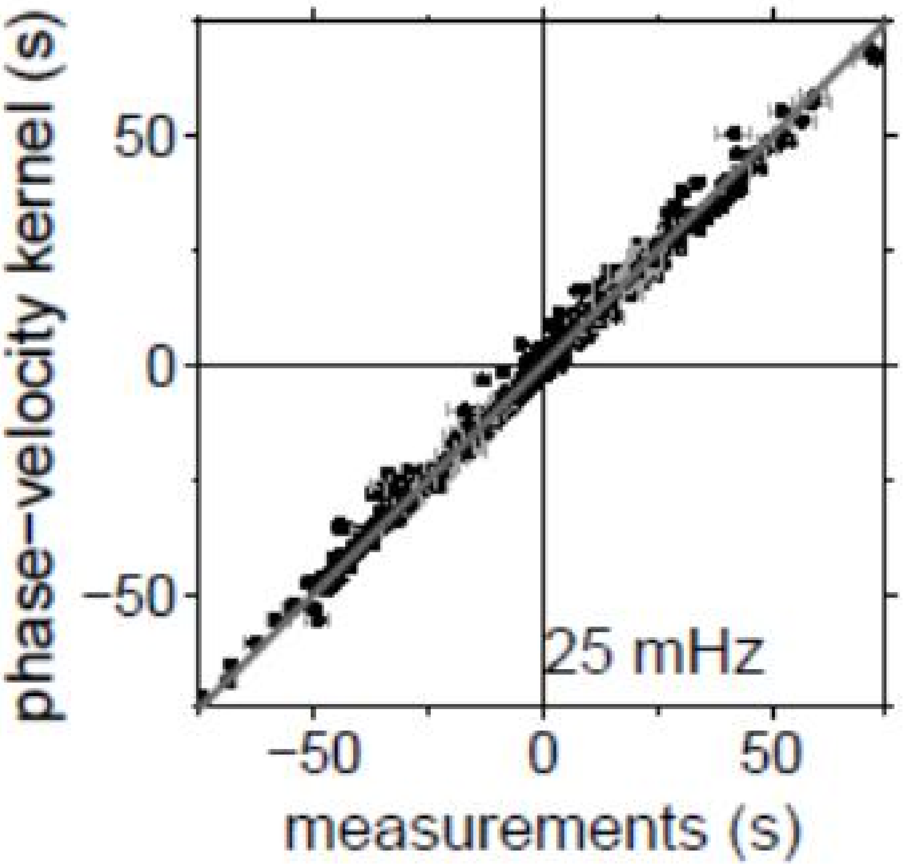
Example seismograms in PREM and CRUST2.0



Liu and Zhou, 2013

Testing model: Crust2.0

kernel prediction *vs* SEM measurements

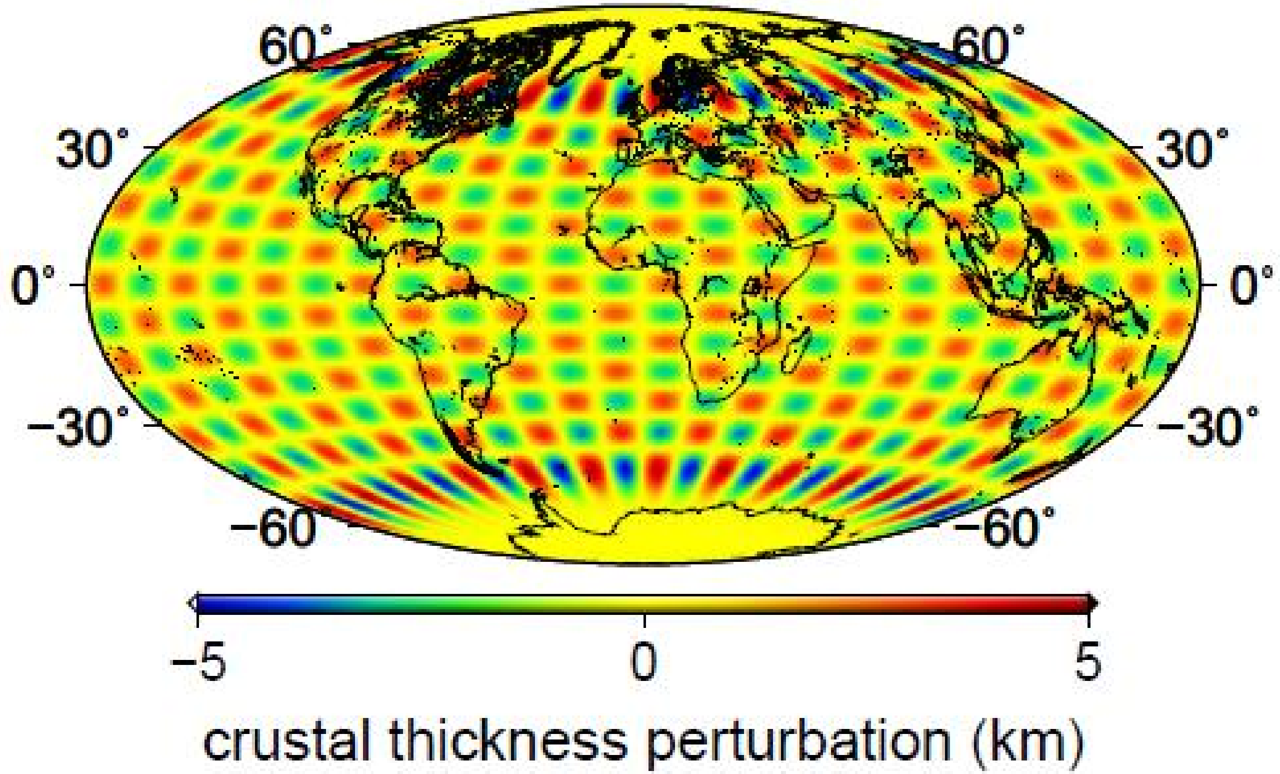


Liu and Zhou, 2013

Model used to test finite-frequency effects

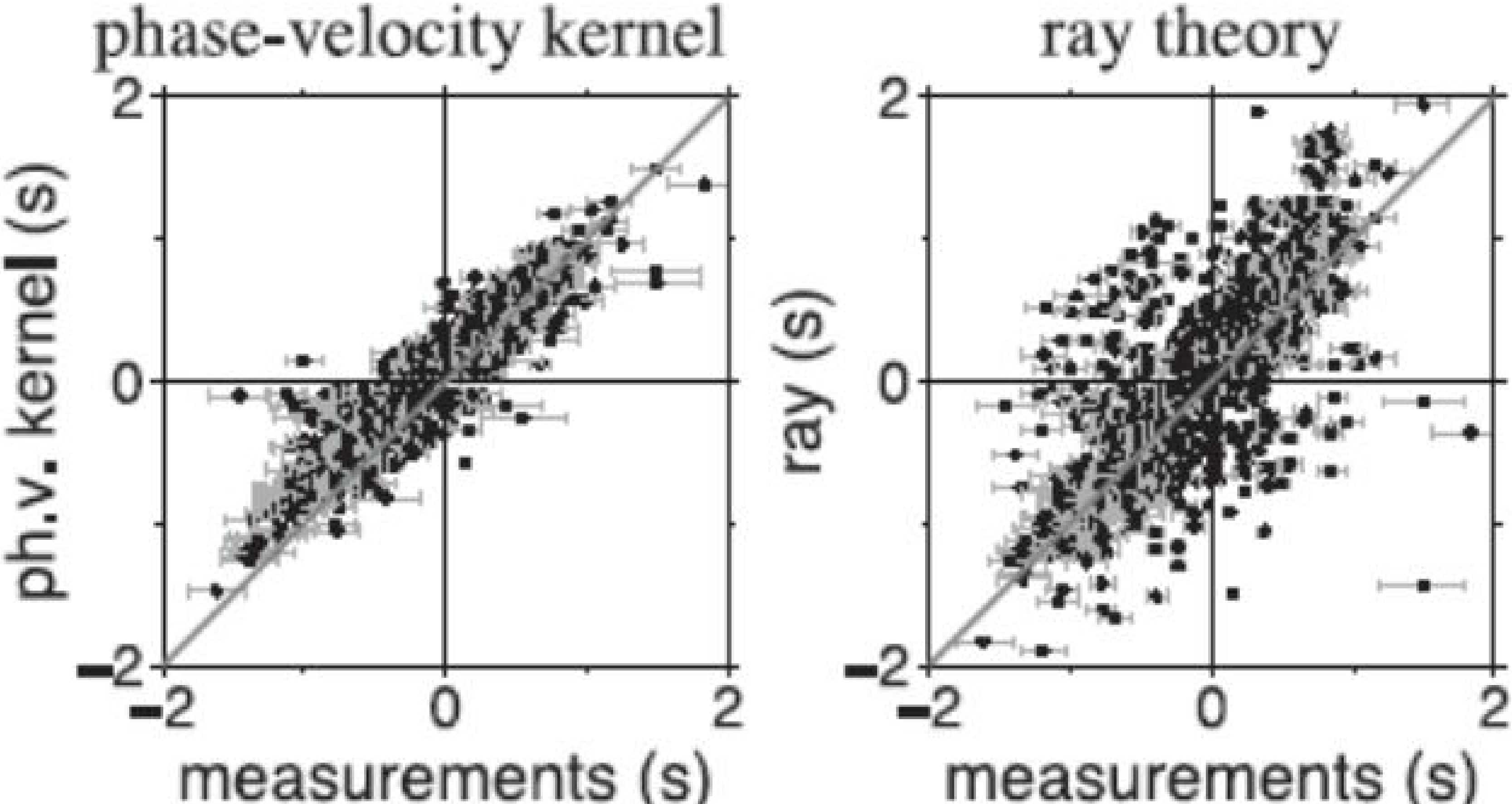
Testing model

Crustal thickness: 24.4 + lateral perturbations



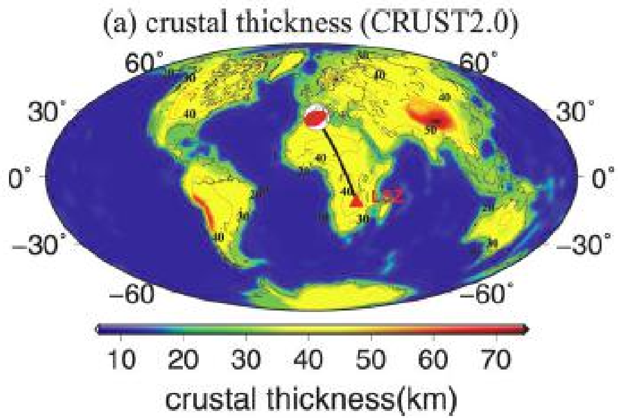
finite-frequency effects

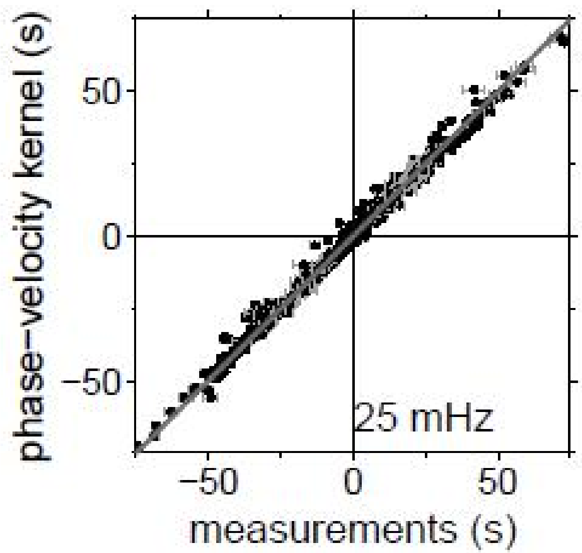
kernel predictions *v.s* SEM measurements



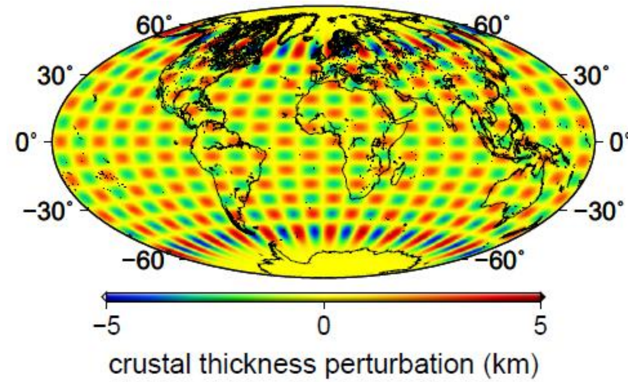
Liu and Zhou, 2013

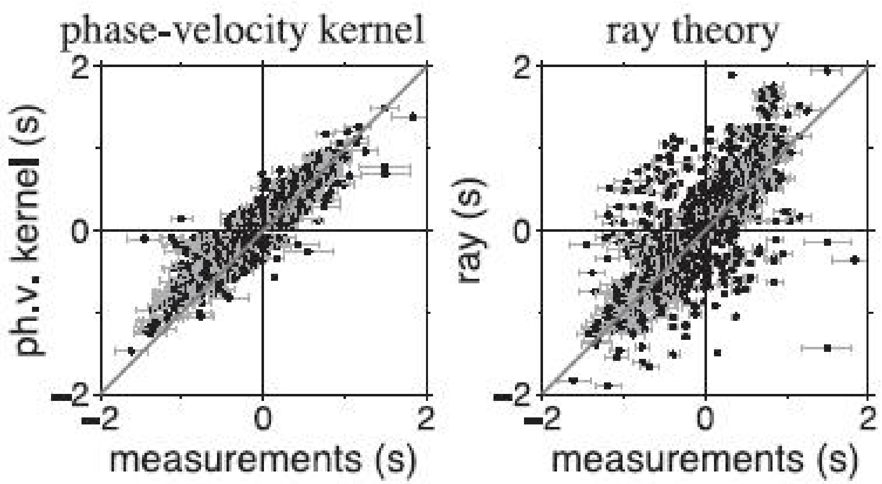
nonlinearity



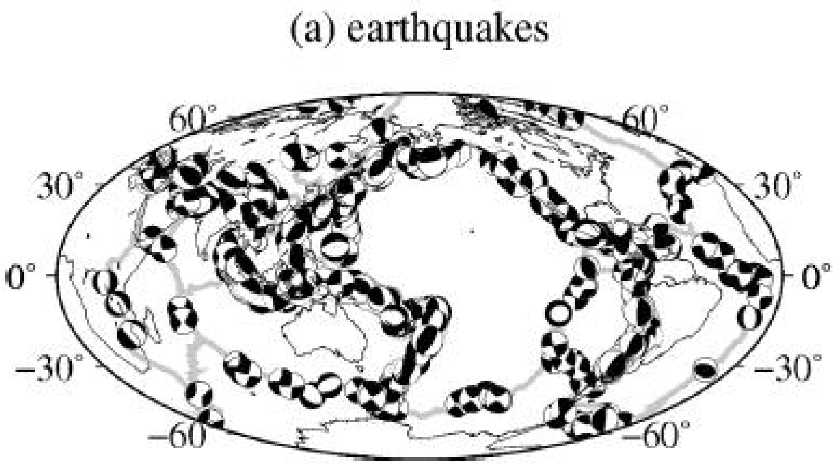


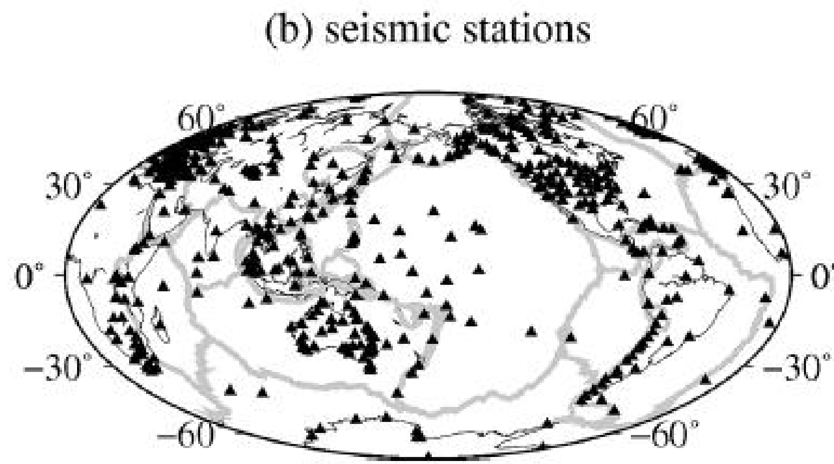
FF effects



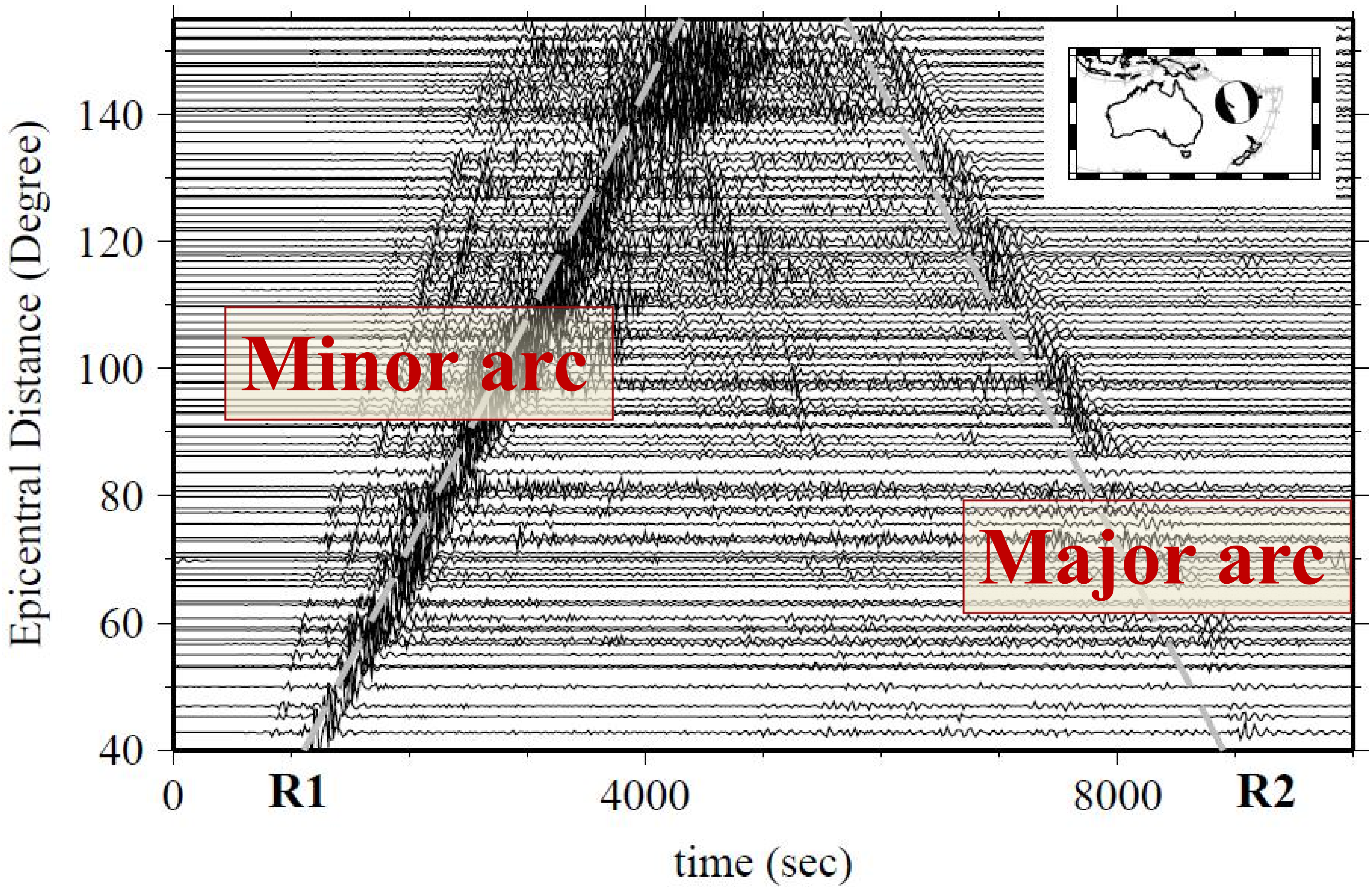


Earthquakes and Stations

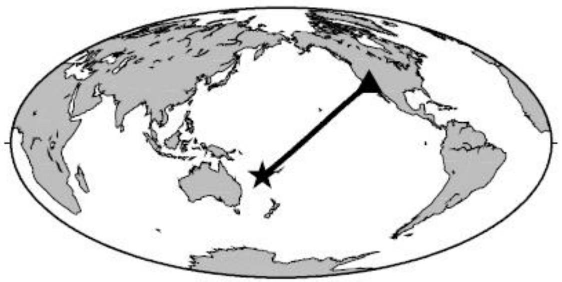


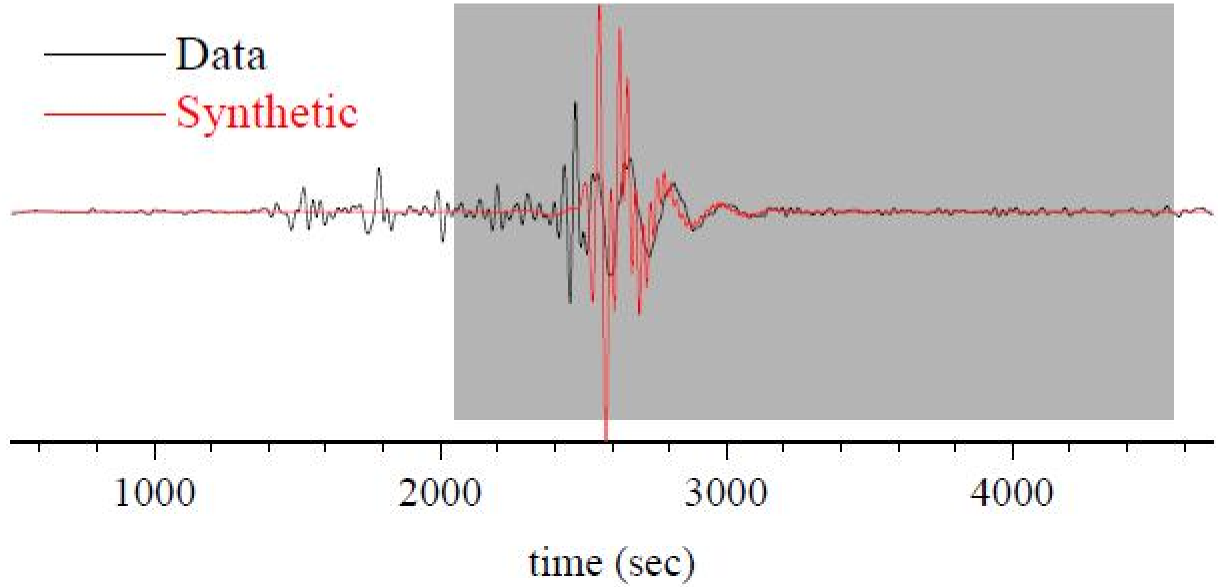


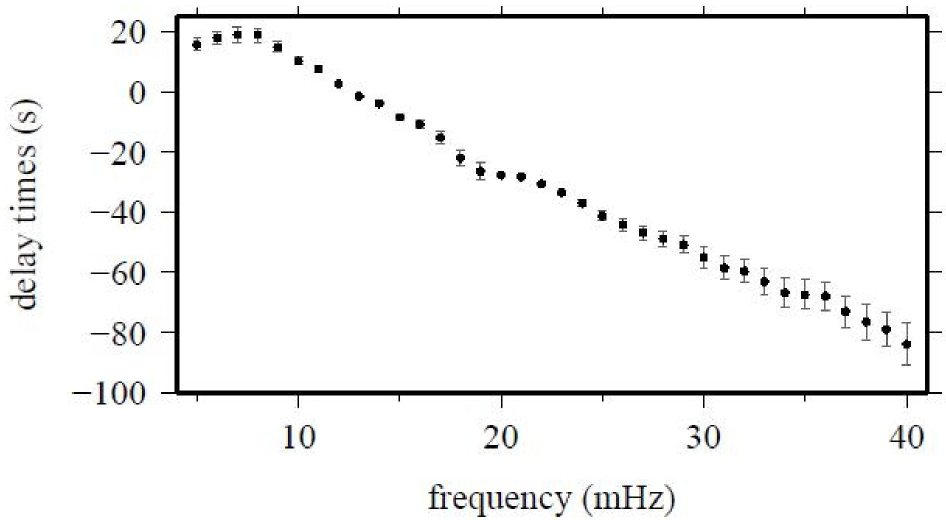
~580 stations
~800 earthquakes

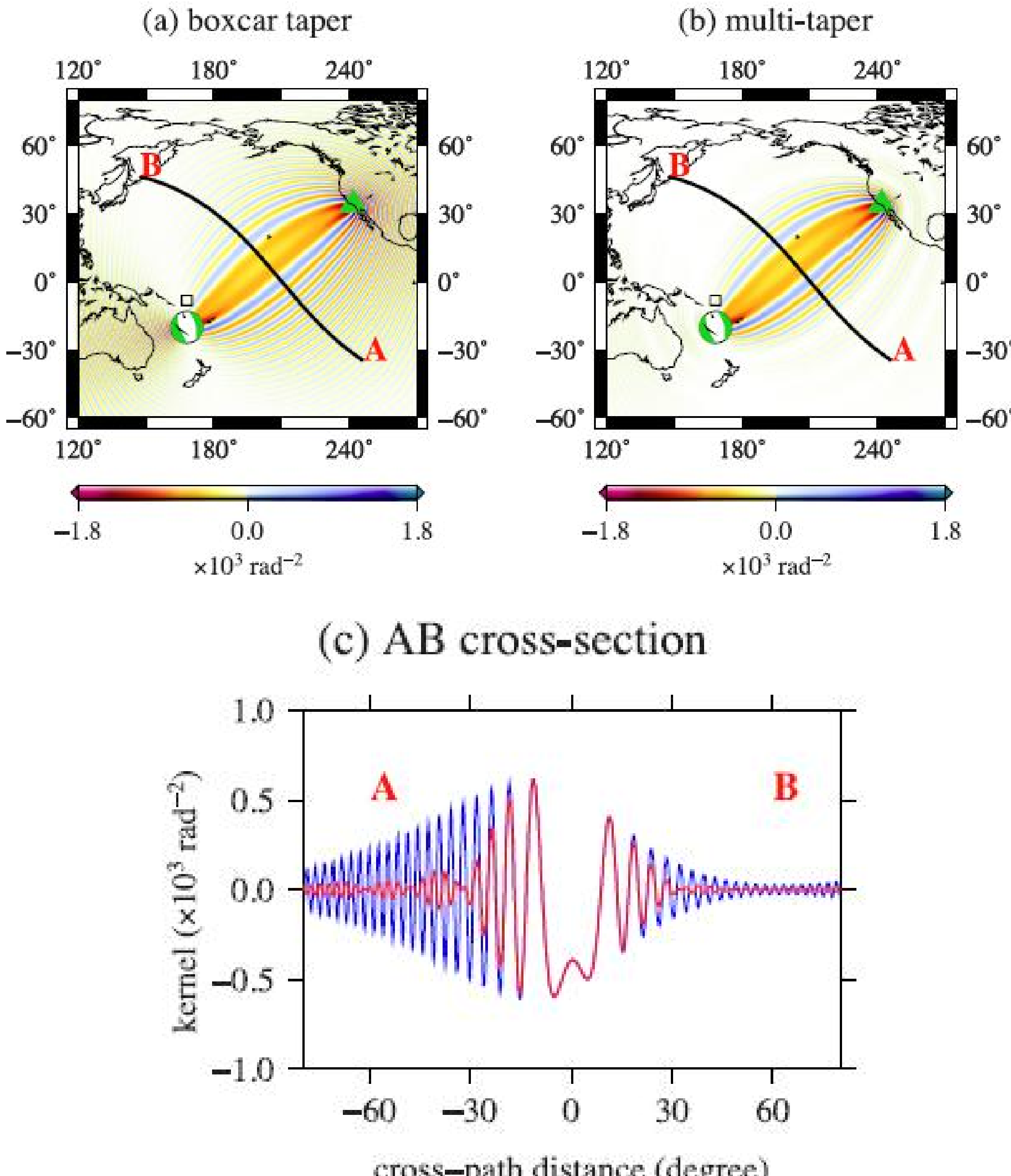


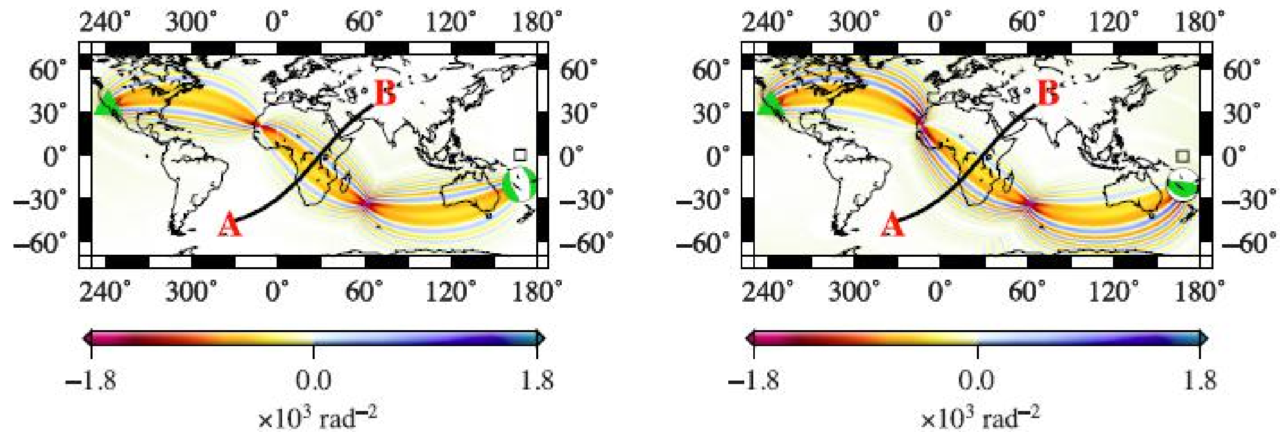
Epicentral Distance (Degree)
140
120
100
80
60
40
Minor arc
Major arc
0
R1
4000
8000
R2
time (sec)



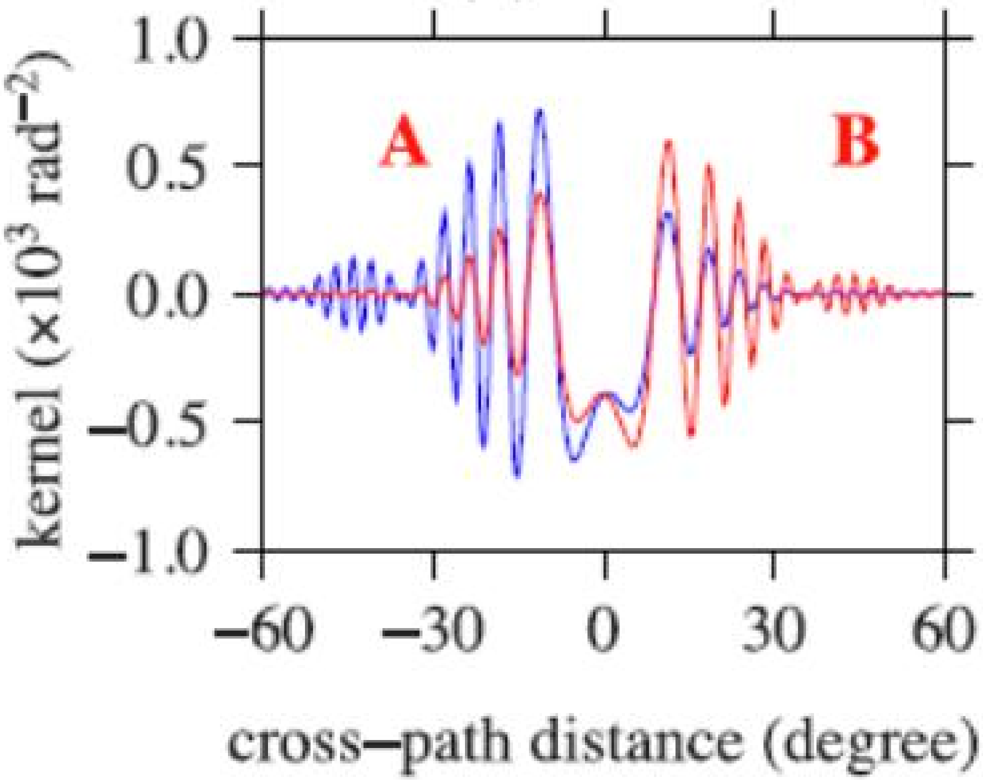

Data
Synthetic
1000
2000
3000
4000
time (sec)


20
0
−20
−40
−60
−80
−100
delay times (s)
10
20
30
40
frequency (mHz)

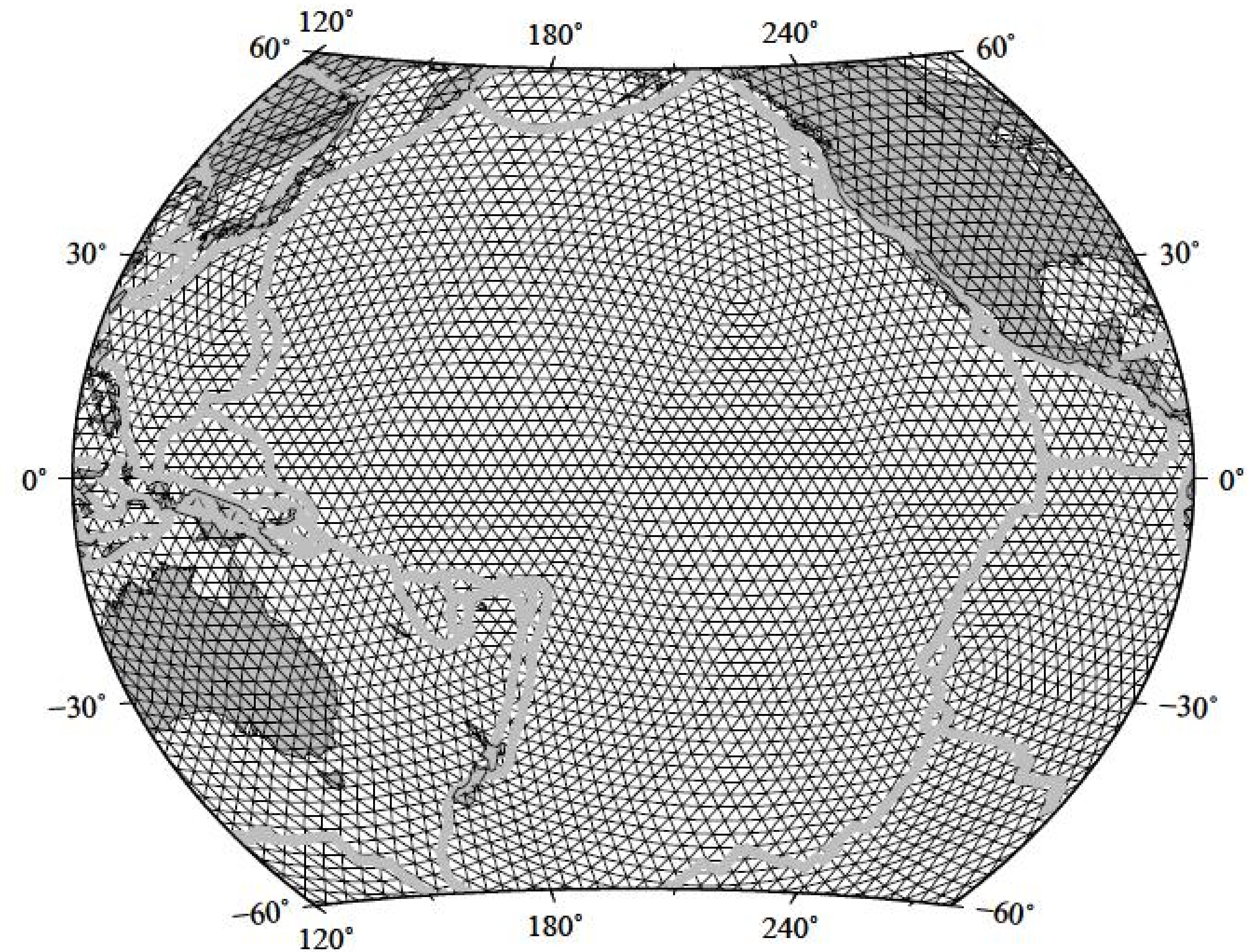

(a) boxcar taper
(b) multi-taper
120°
180°
240°
60°
30°
0°
−30°
−60°
A
B
−1.8
0.0
1.8
×10³ rad⁻²
(c) AB cross-section
kernel (×10³ rad⁻²)
cross−path distance (degree)
1.0
0.5
0.0
−0.5
−1.0
−60
−30
0
30
60


240° 300° 0° 60° 120° 180°
60° 30° 0° −30° −60°
A
B
−1.8 0.0 1.8
×10³ rad⁻²

(c)


A
B
1.0
0.5
0.0
−0.5
−1.0
kernel (×10³ rad⁻²)
−60 −30 0 30 60
cross−path distance (degree)

Model parameterization



Inverse problem

$$\delta\varphi(\omega) = \iint K(\omega, x)\ \delta \ln c(\omega, x)\, d\Omega$$

discretization and model parameterization

$$b = Ax$$

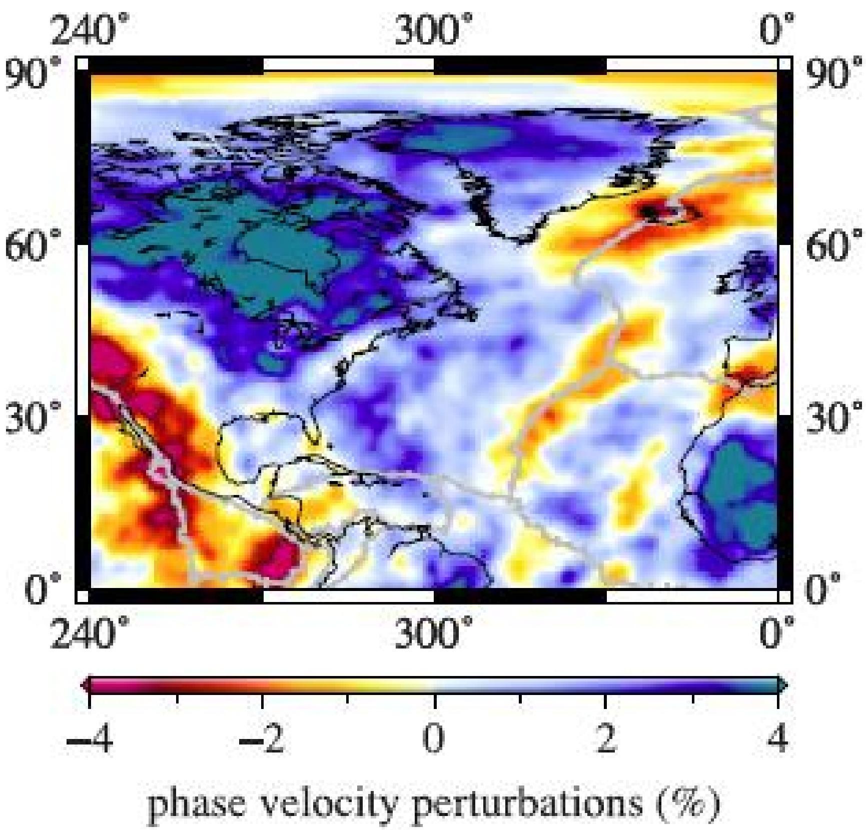
Solving inverse problem with SVD

$$\mathbf{x} = \sum_{i=1}^{M} \left(\frac{\mathbf{u}_i^T \mathbf{b}}{\lambda_i} \right) \mathbf{u}_i$$

Finite-frequency effects:

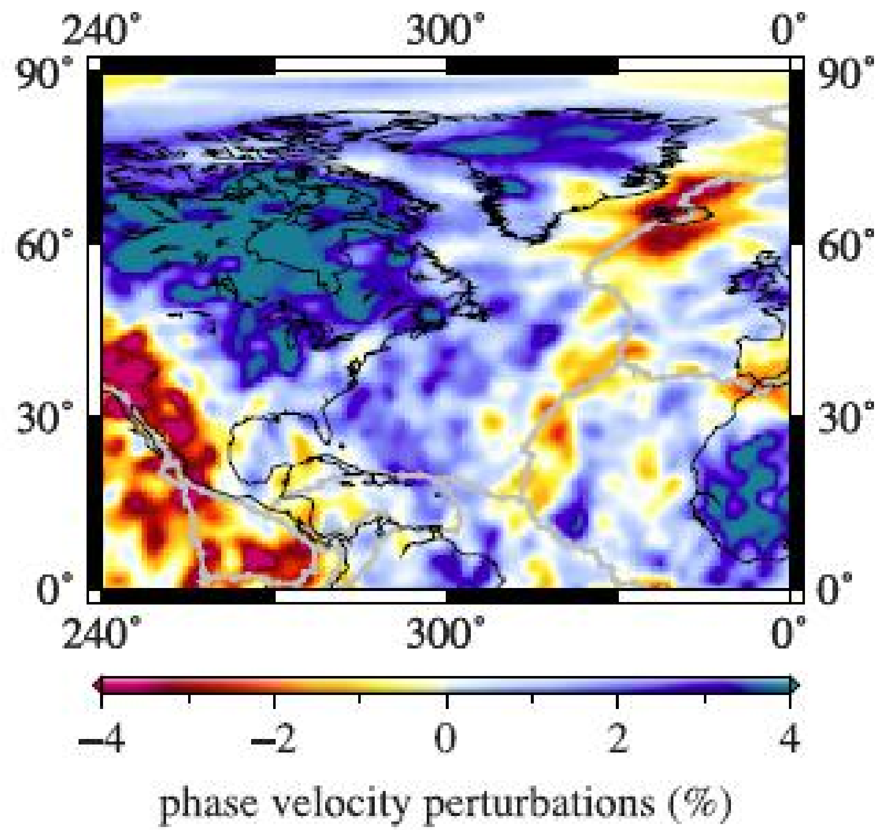
kernel

(a) finite-frequency model



ray

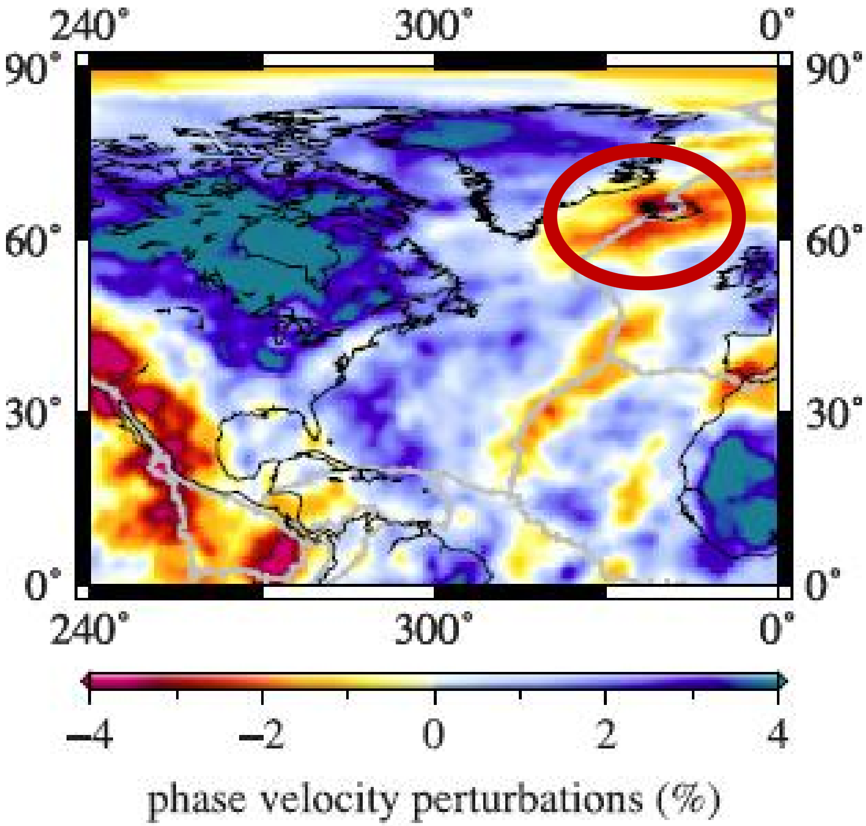
(b) ray-theoretical model



Finite-frequency effects:

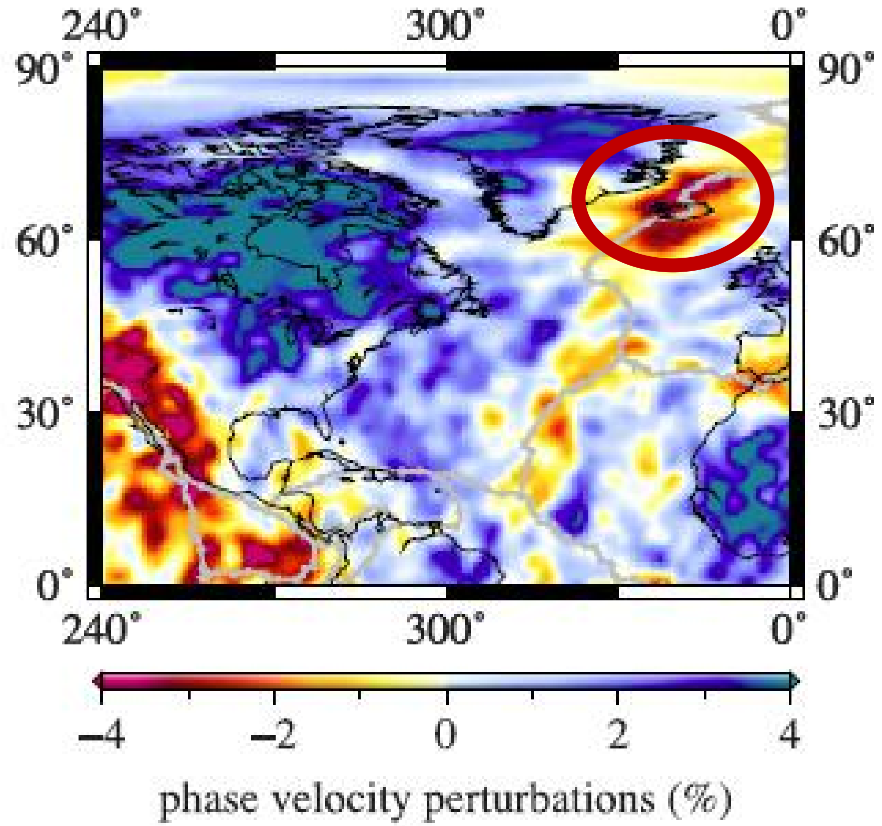
kernel

(a) finite-frequency model



ray

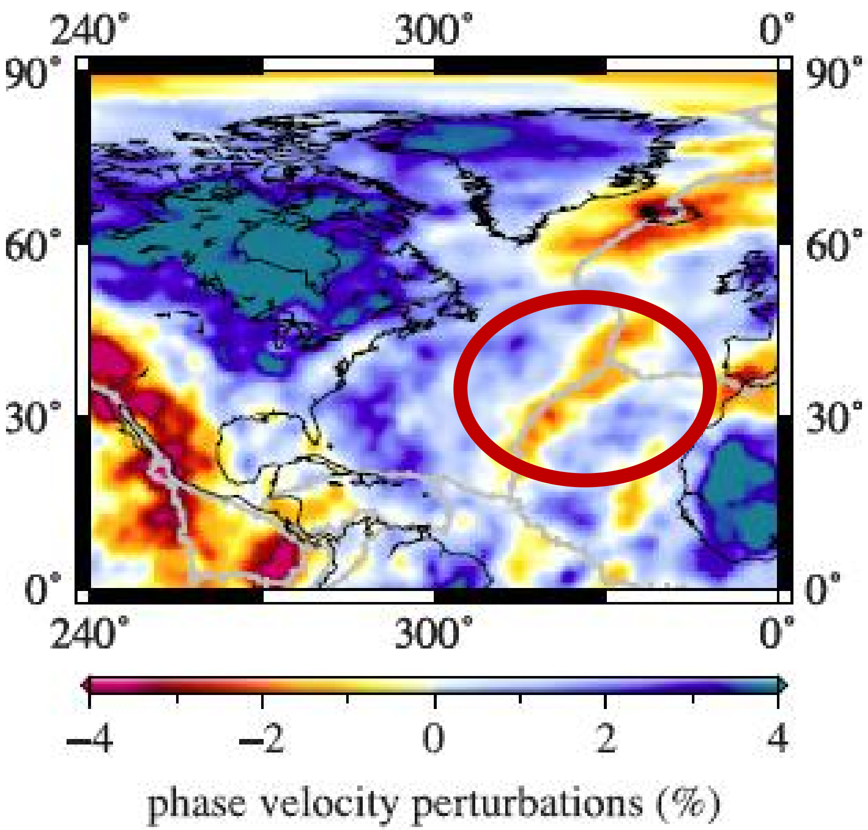
(b) ray-theoretical model



Finite-frequency effects:

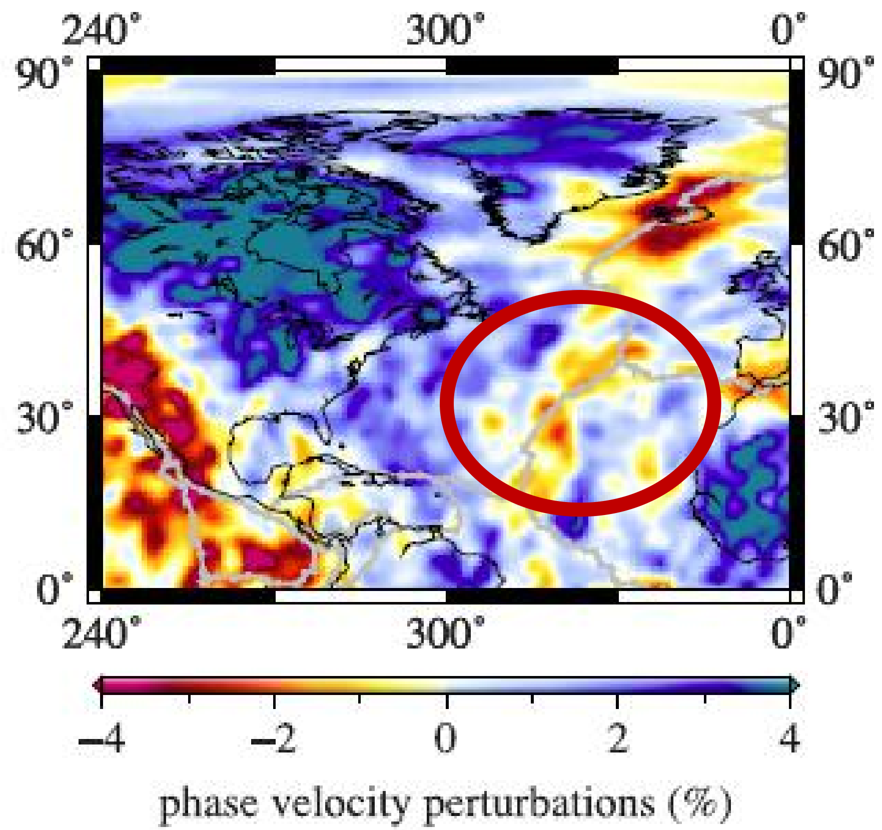
kernel

(a) finite-frequency model

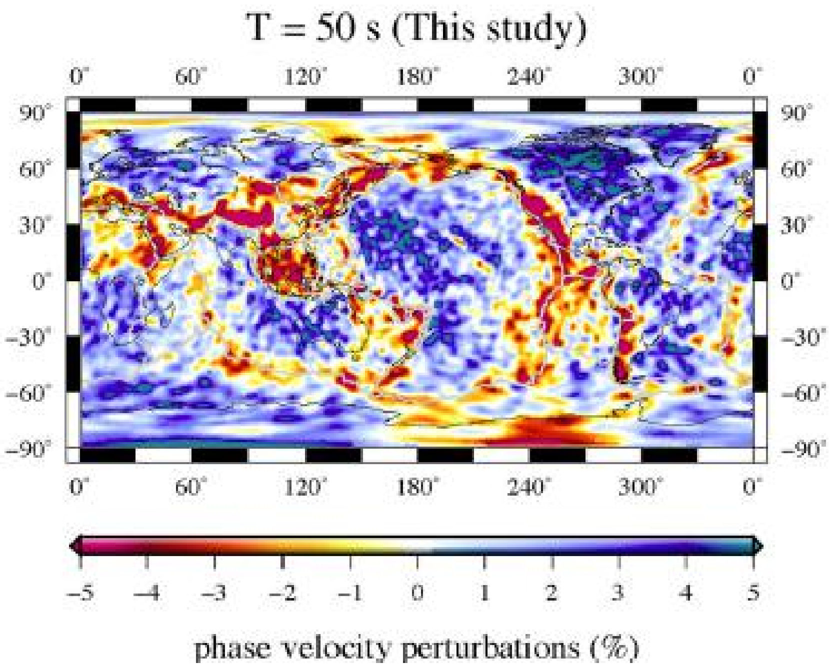


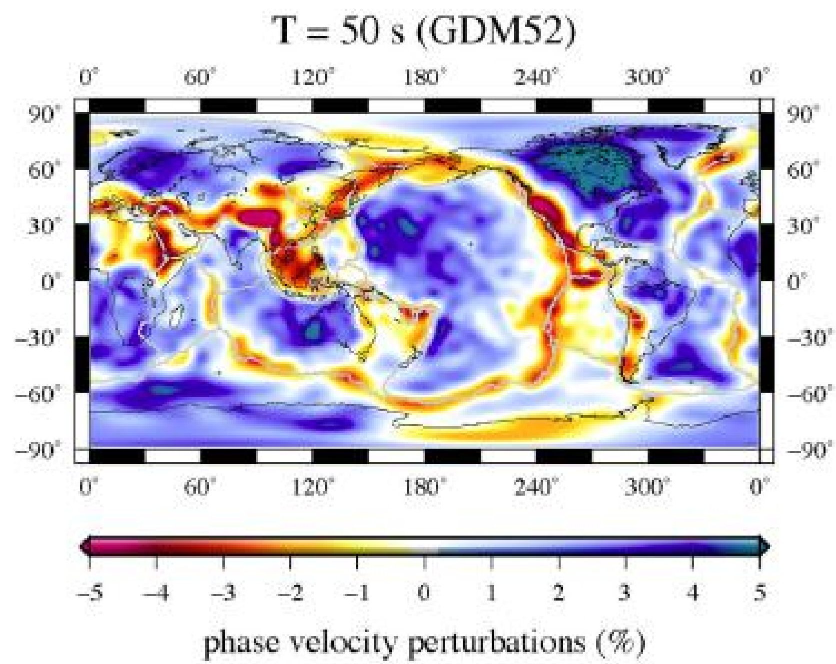
ray

(b) ray-theoretical model

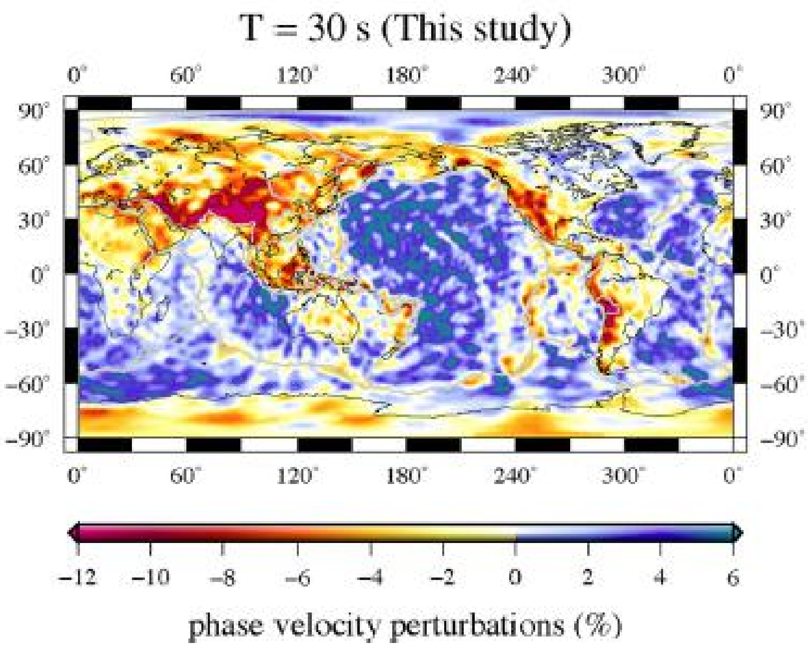


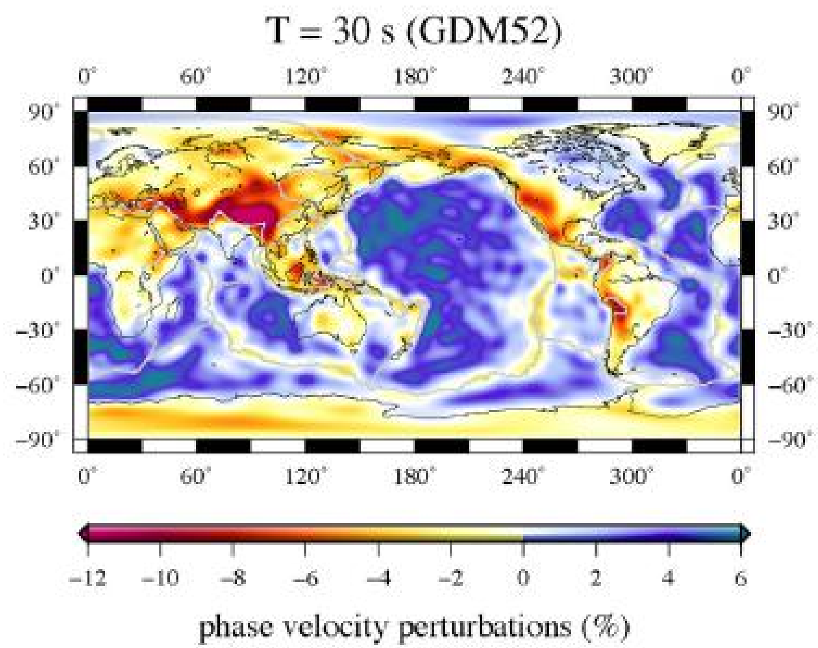
Phase velocity maps



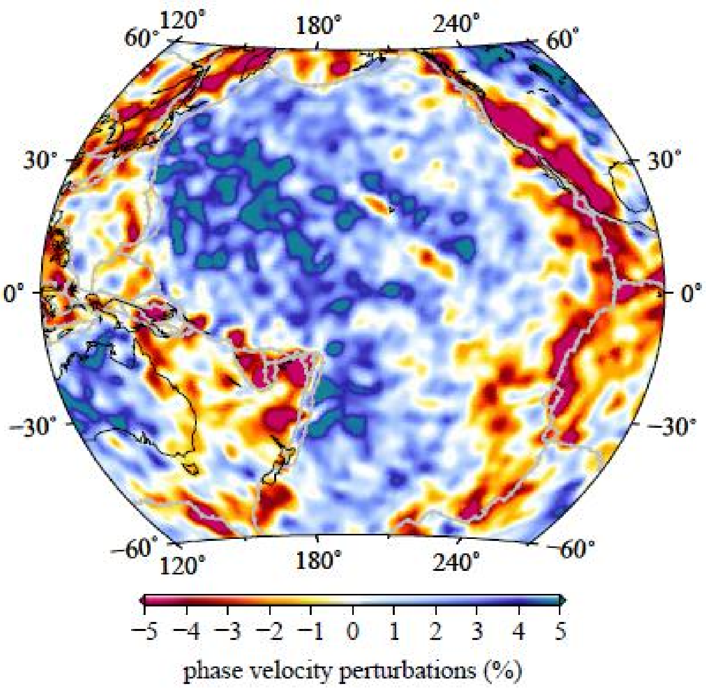


Phase velocity maps

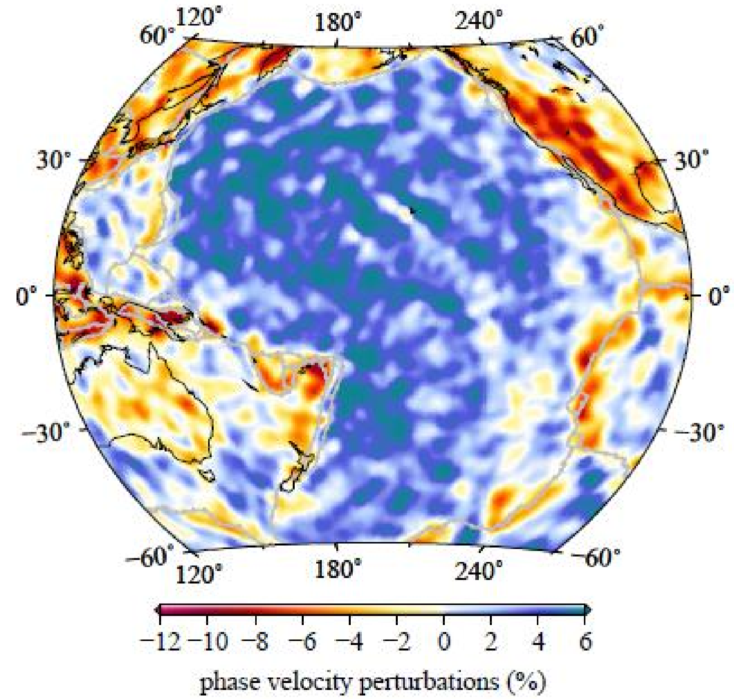




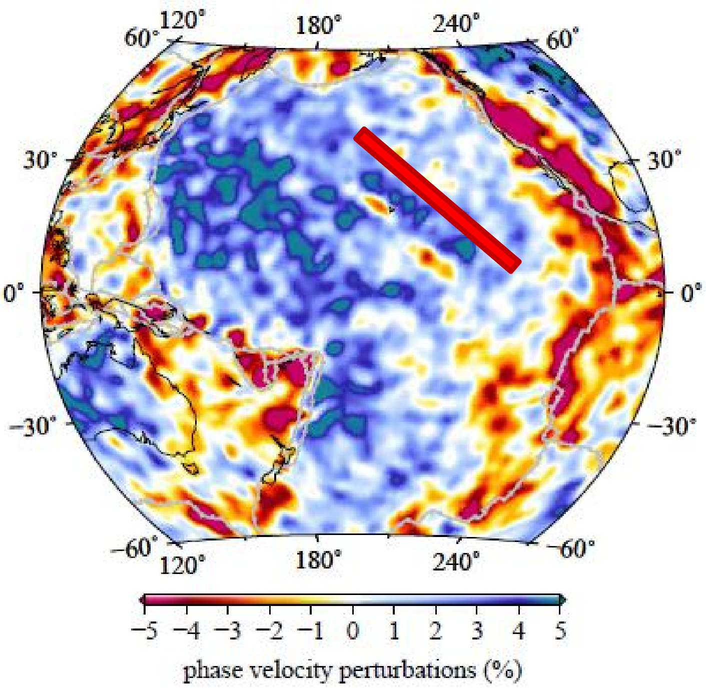
50 s


120°
180°
240°
60°
30°
0°
−30°
−60°
−5 −4 −3 −2 −1 0 1 2 3 4 5
phase velocity perturbations (%)

30 s

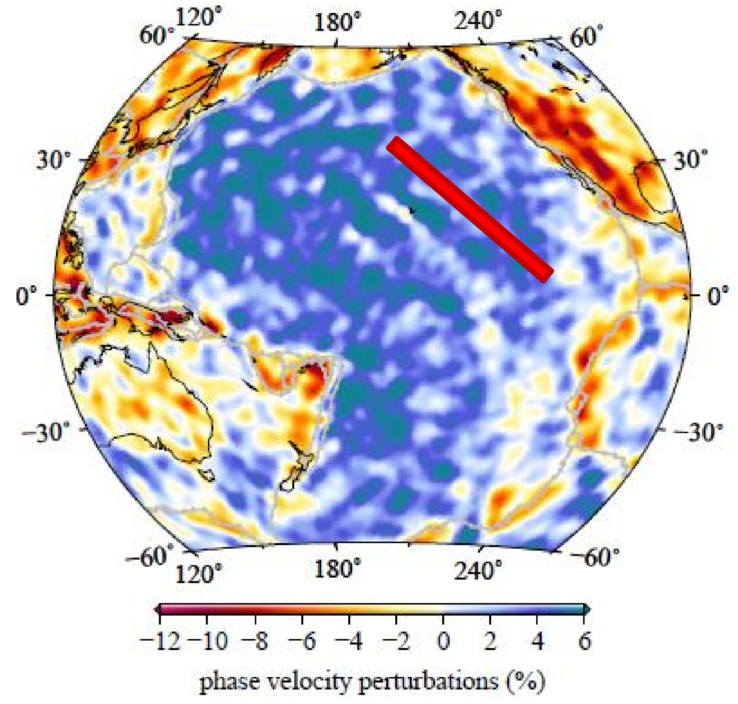

120°
180°
240°
60°
30°
0°
−30°
−60°
−12 −10 −8 −6 −4 −2 0 2 4 6
phase velocity perturbations (%)

50 s



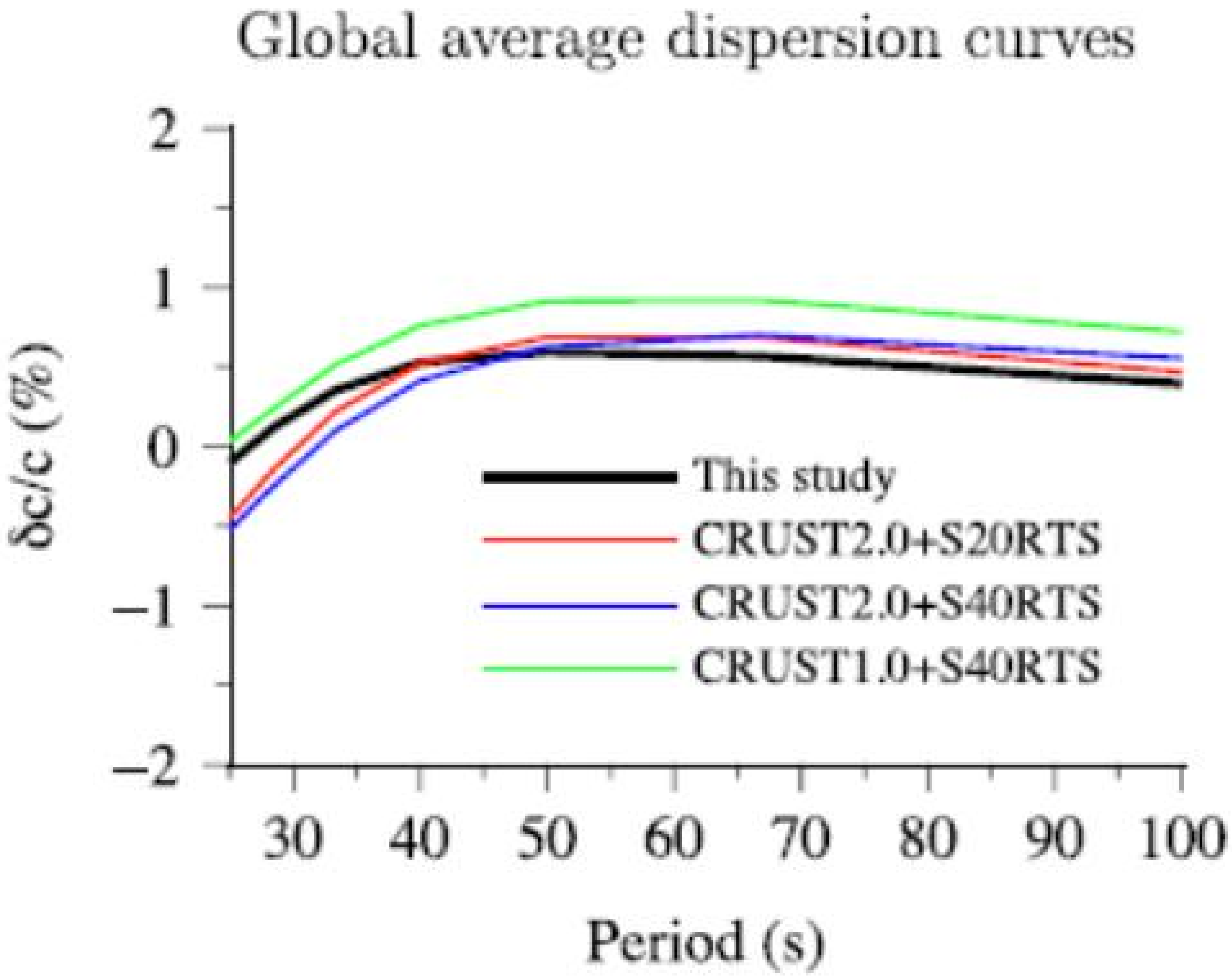
120°
180°
240°
60°
60°
30°
30°
0°
0°
−30°
−30°
−60°
−60°
120°
180°
240°
−5 −4 −3 −2 −1 0 1 2 3 4 5
phase velocity perturbations (%)

30 s



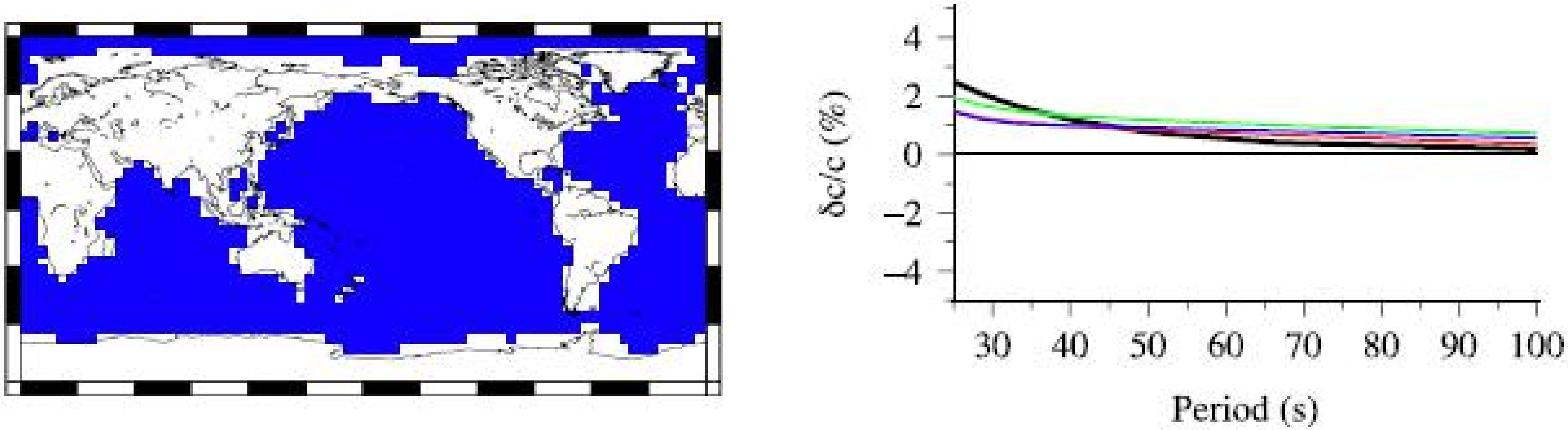
120°
180°
240°
60°
60°
30°
30°
0°
0°
−30°
−30°
−60°
−60°
120°
180°
240°
−12 −10 −8 −6 −4 −2 0 2 4 6
phase velocity perturbations (%)

Global average



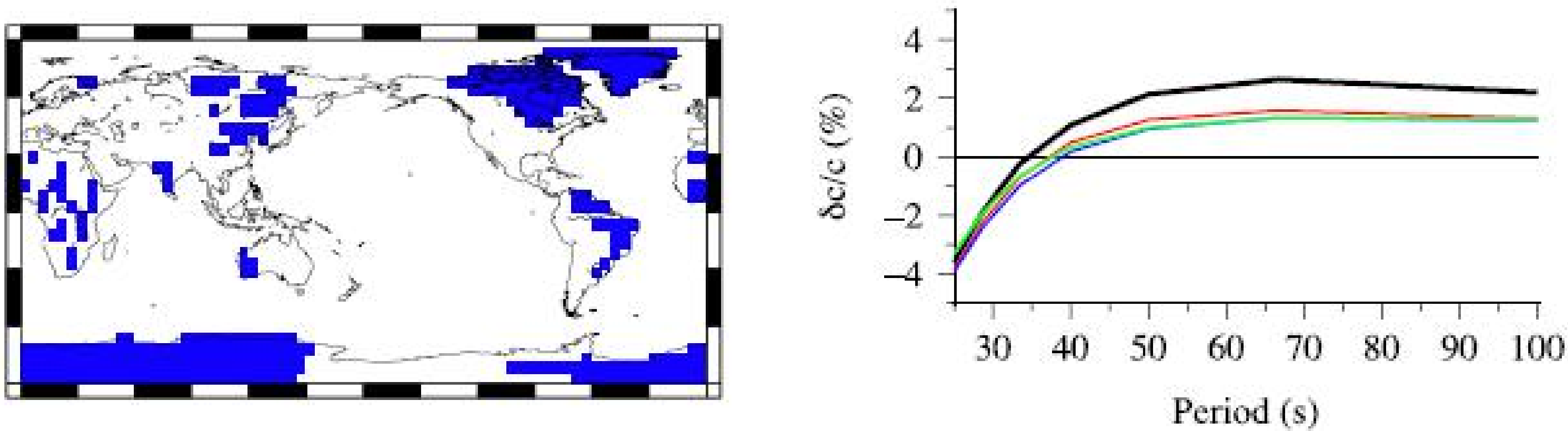
Global average in oceanic basins

(a) Ocean (60%)



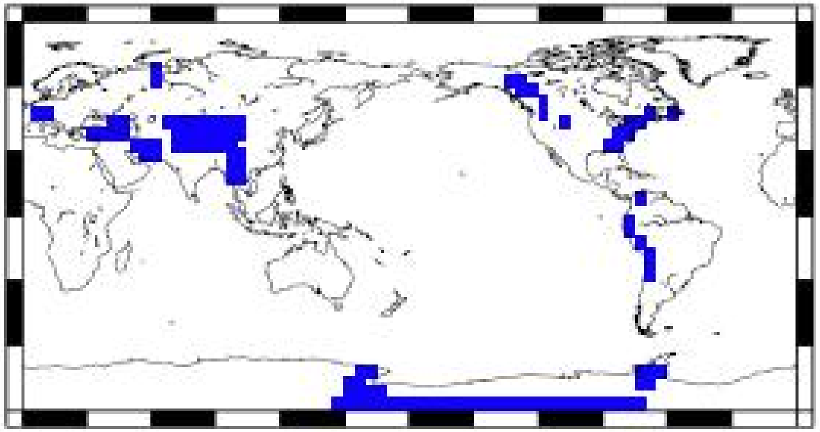
Archean Cratons

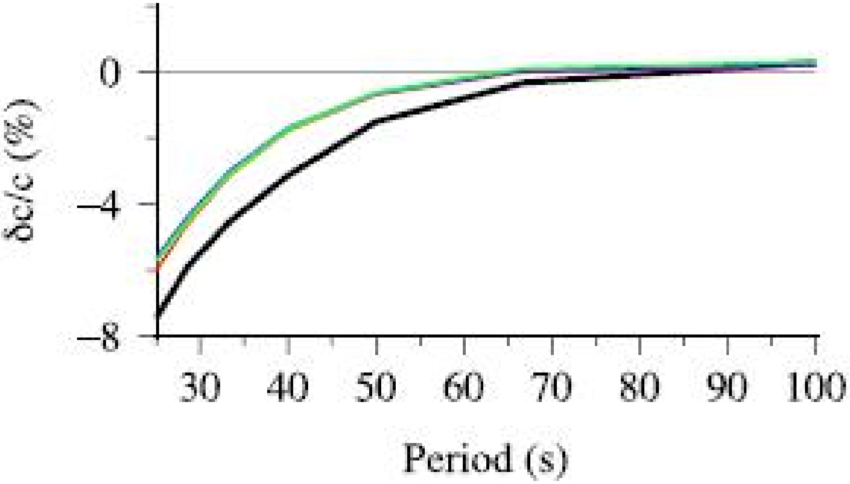
(b) Archean (8%)



Orogenic regions

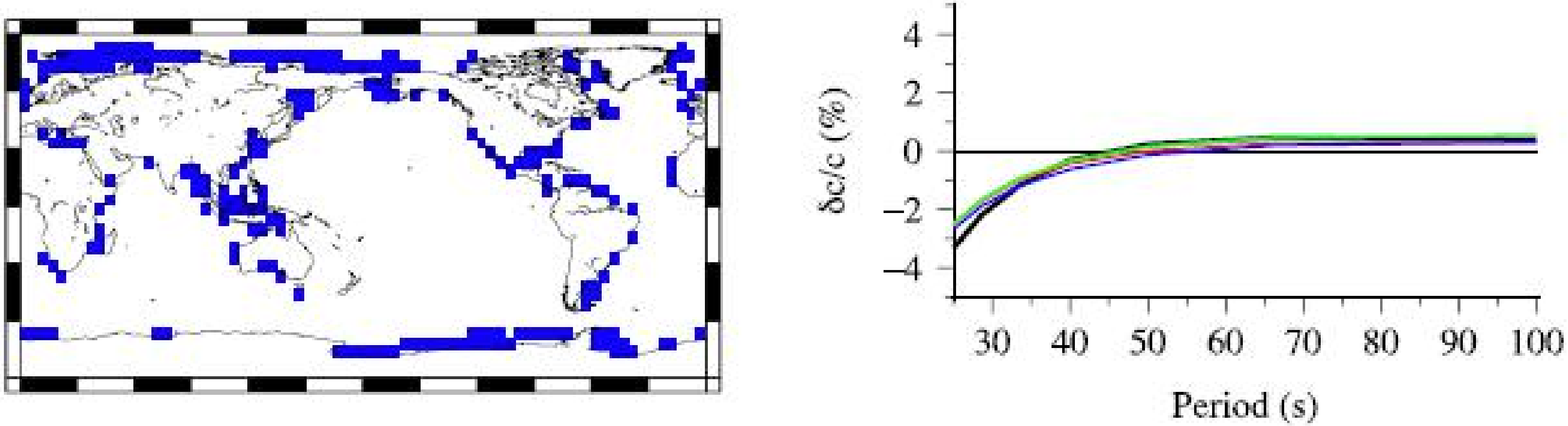
(c) Orogen (3%)





Shelf/Slope

(b) Shelf/slope (8%)



Conclusion

- We apply finite-frequency phase-velocity kernels to our global data set of Rayleigh-wave dispersion measurements and obtain global phase velocity maps;

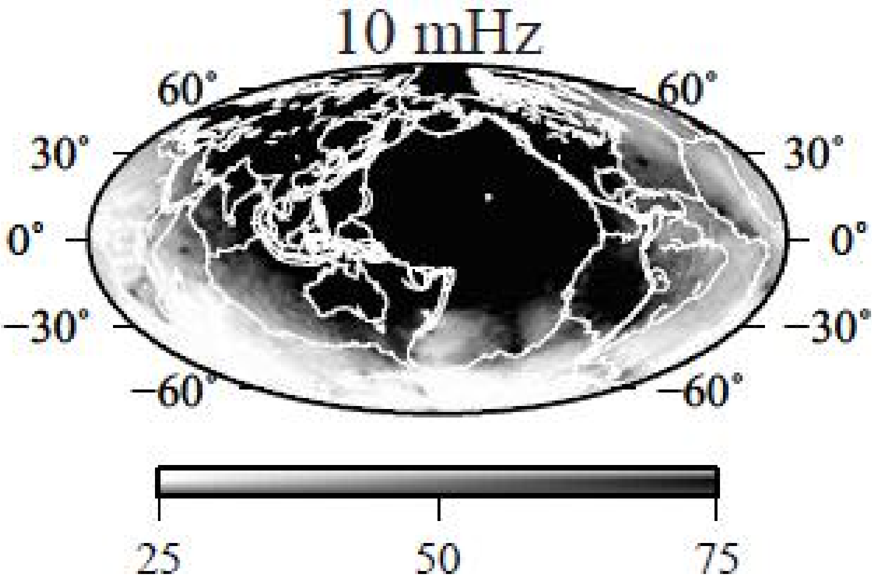
- Our results show northwest trending small-scale structure in the Pacific;

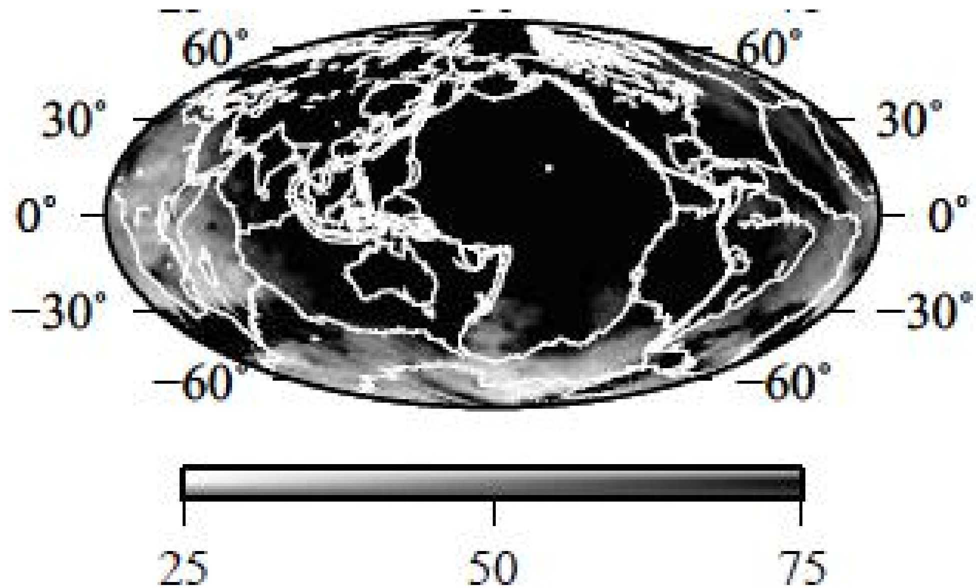
- Our results indicate a thinner crustal or faster wave speed in the oceanic regions, consistent with CRUST1.0.

Thanks!

Effect of including major-arc

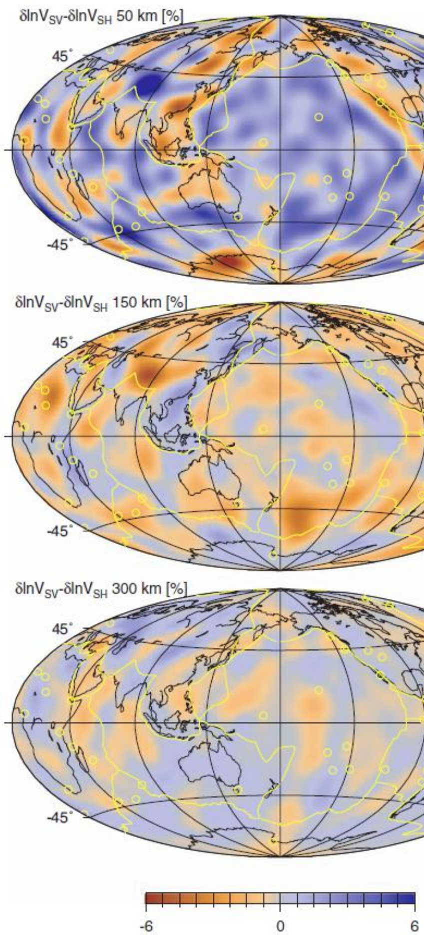
Sensitivity---total length of ray





Importance : understanding nature of LAB

Artificial anisotropy from uncorrected crustal effects

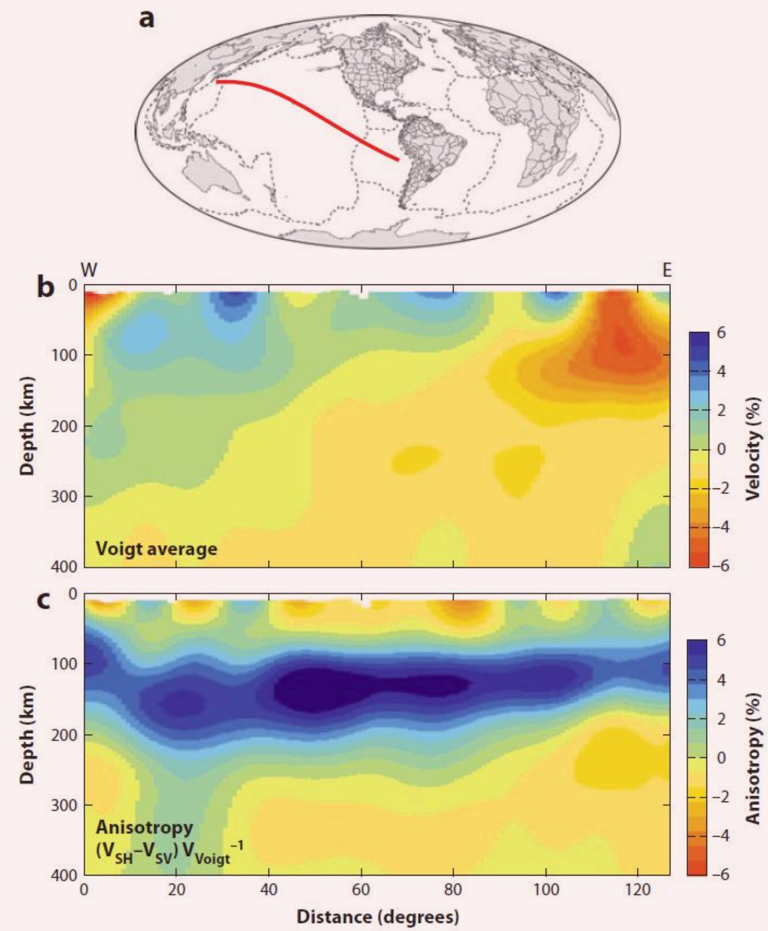


Bozdag and Trampert 2008

Tomographic model from real data

Velocity

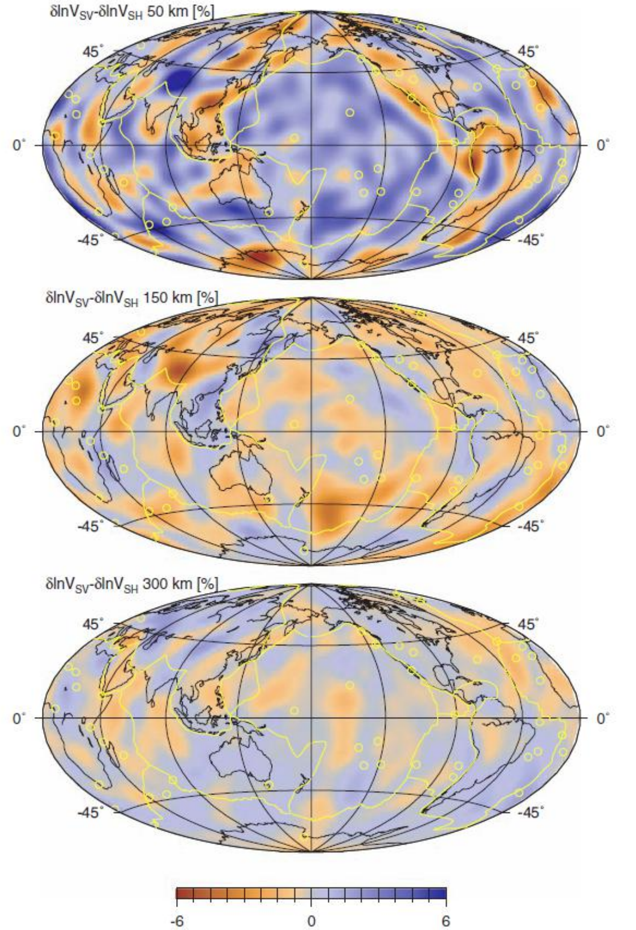
Anisotropy



Kustowski et al. 2008

Importance : understanding nature of LAB

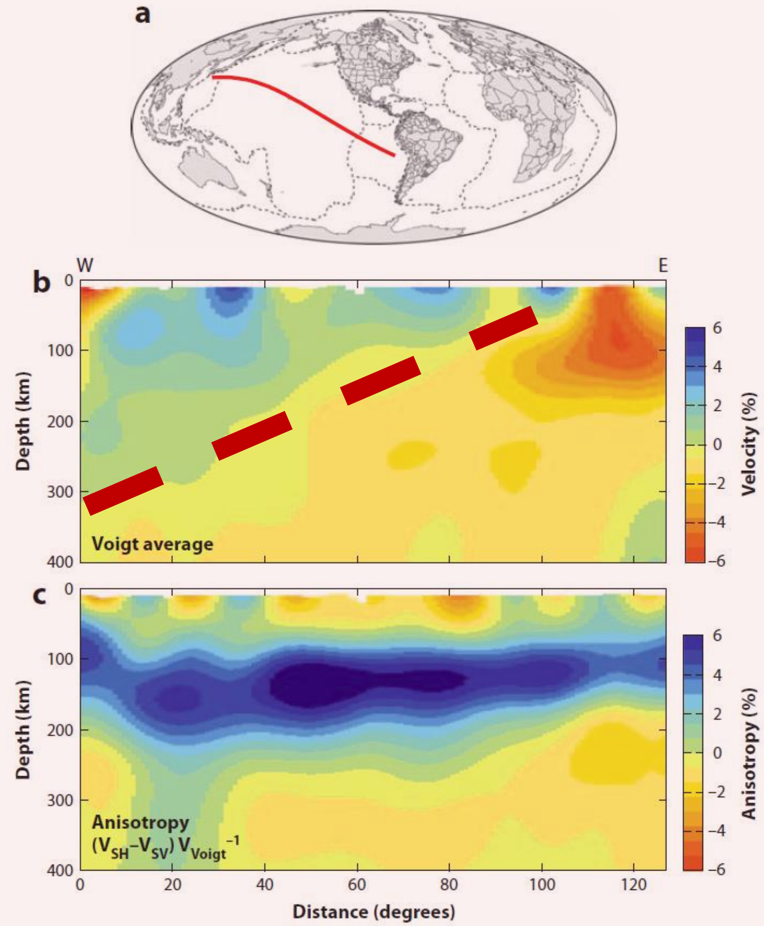
Artificial anisotropy from uncorrected crustal effects



Bozdag and Trampert 2008

Tomographic model from real data

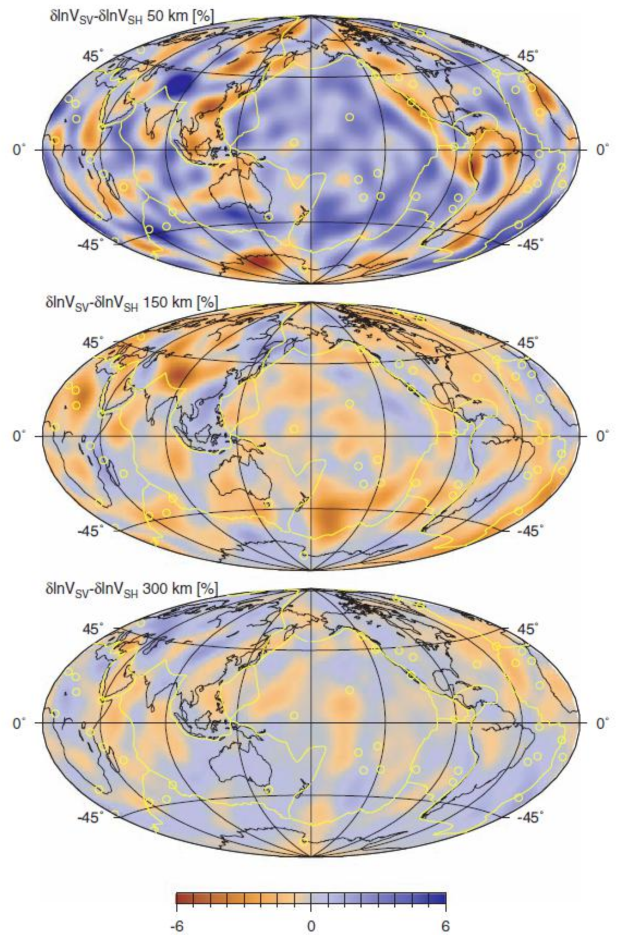
Velocity



Kustowski et al. 2008

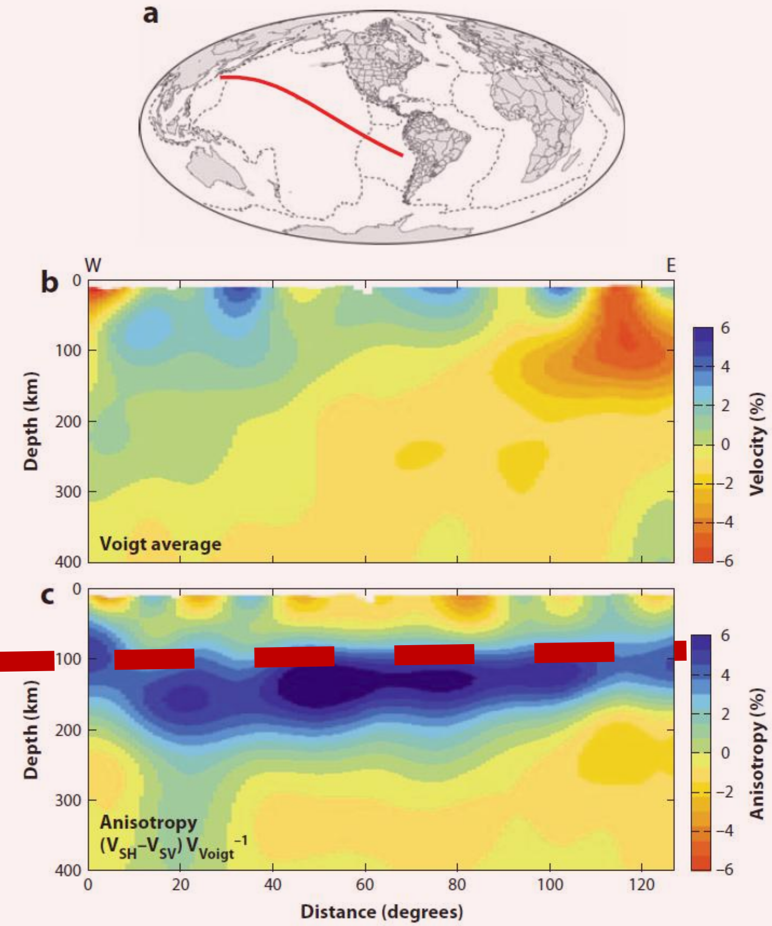
Importance : understanding nature of LAB

Artificial anisotropy from uncorrected crustal effects



Bozdag and Trampert 2008

Tomographic model from real data



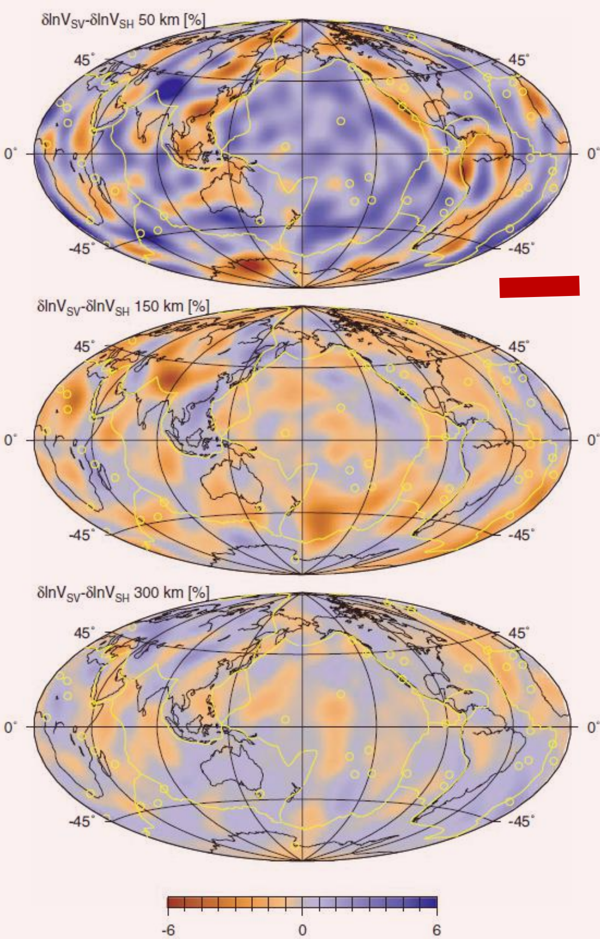
$V_{SH} < V_{SV}$

$V_{SH} > V_{SV}$

Kustowski et al. 2008

Importance : understanding nature of LAB

Artificial anisotropy from uncorrected crustal effects



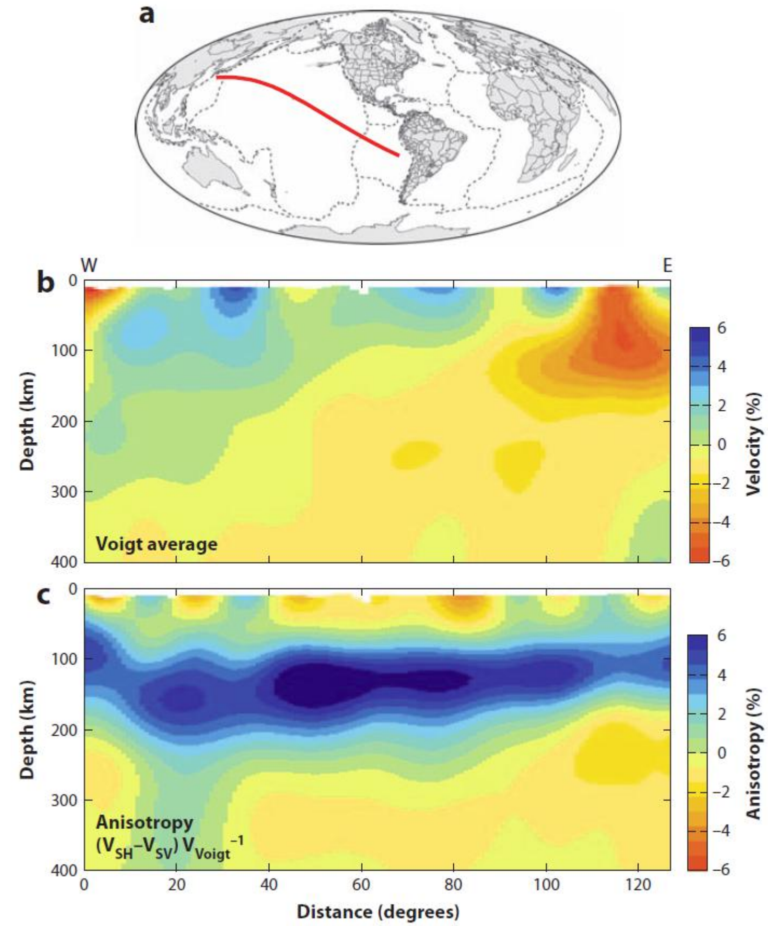
$V_{SH} < V_{SV}$

~100 km

$V_{SH} > V_{SV}$

Bozdag and Trampert 2008

Tomographic model from real data



Kustowski et al. 2008

Checkerboard resolution test