‘Sharp sides’ in mantle convection

Seismic multipathing in thermal and thermochemical models

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Hein van Heck[3], Rhodri Davies[4], J Huw Davies[3], James Wookey[2]

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The Leverhulme Trust

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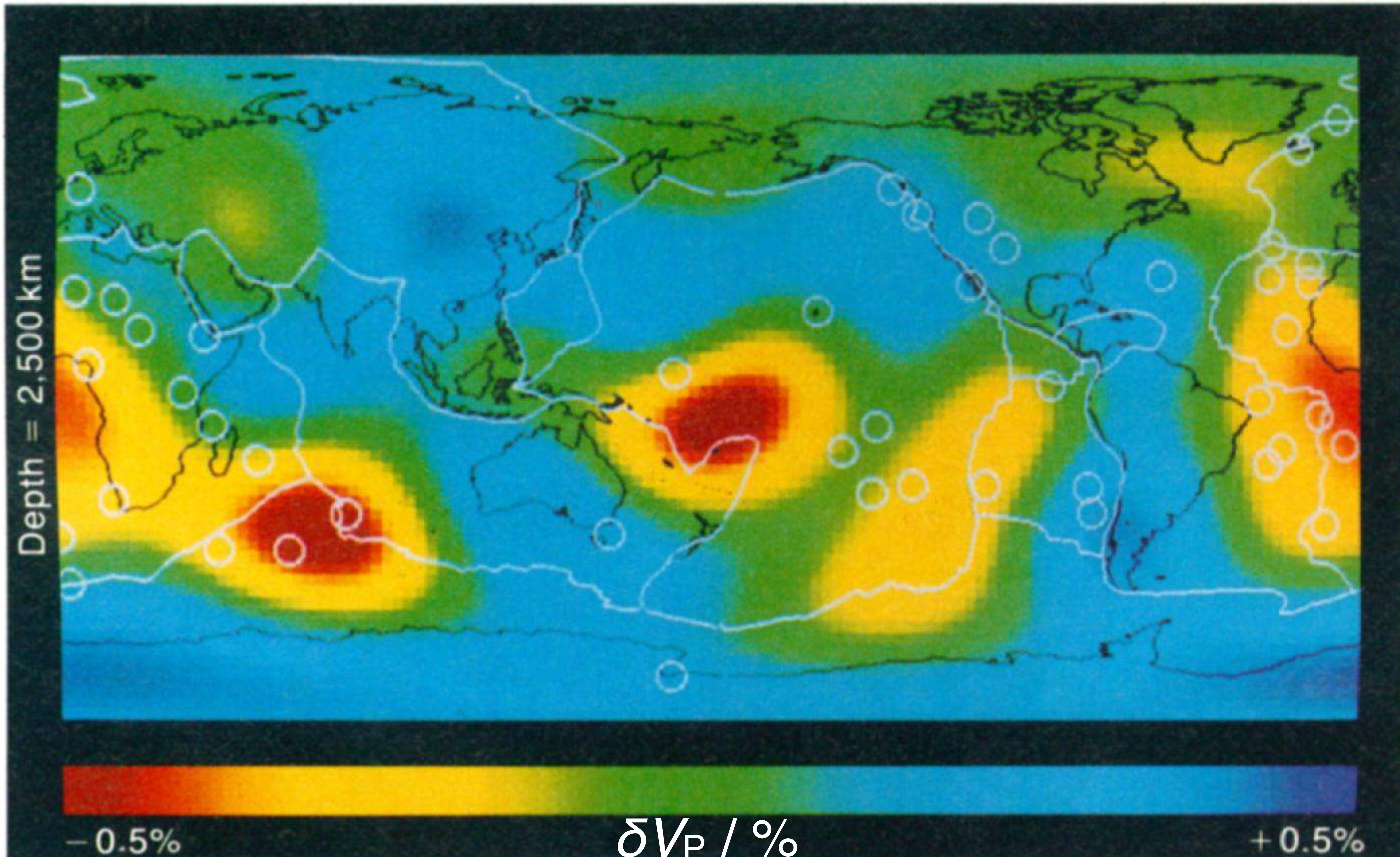
Australian National University

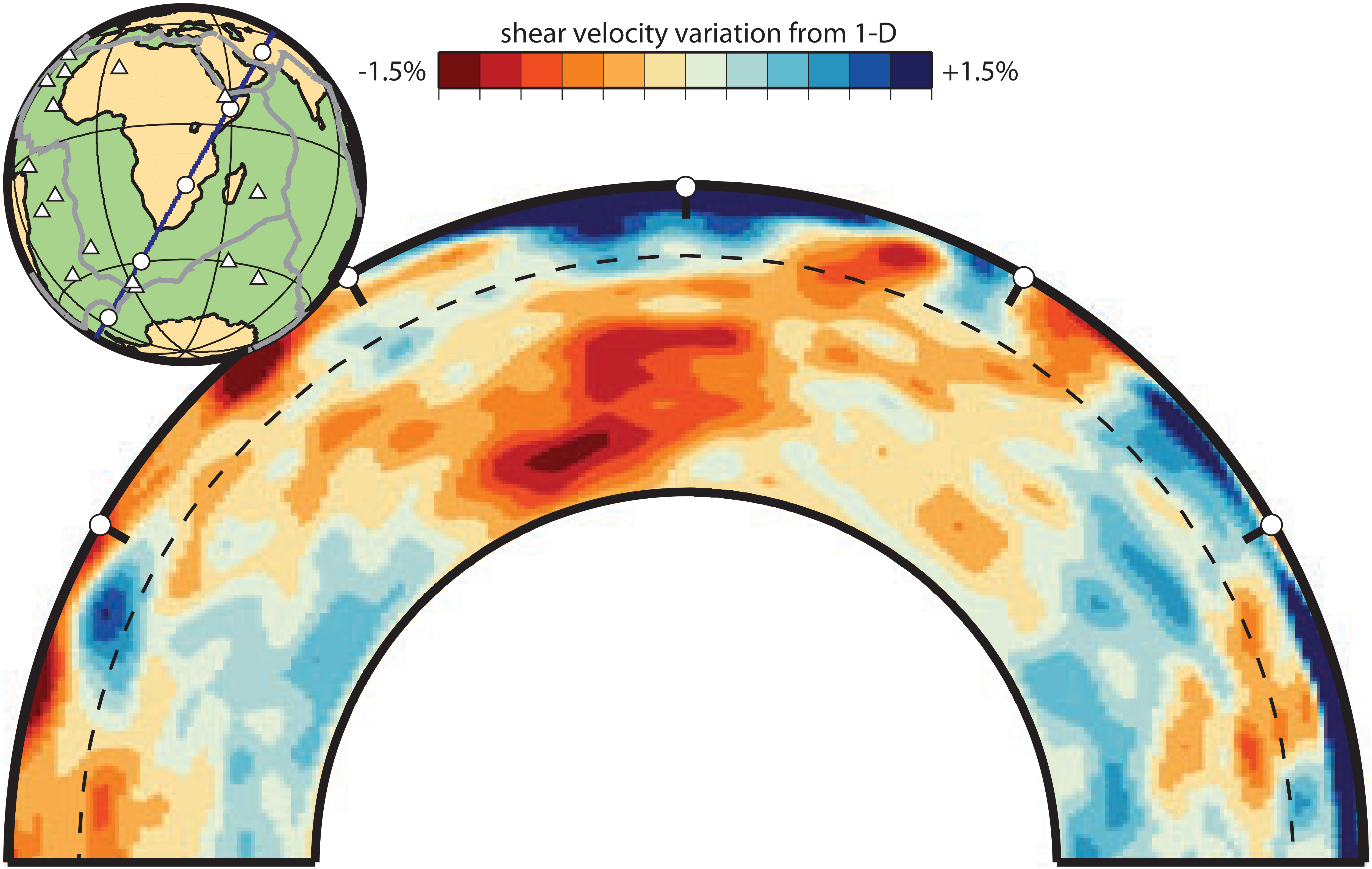
archer

The 3D Earth, 1984



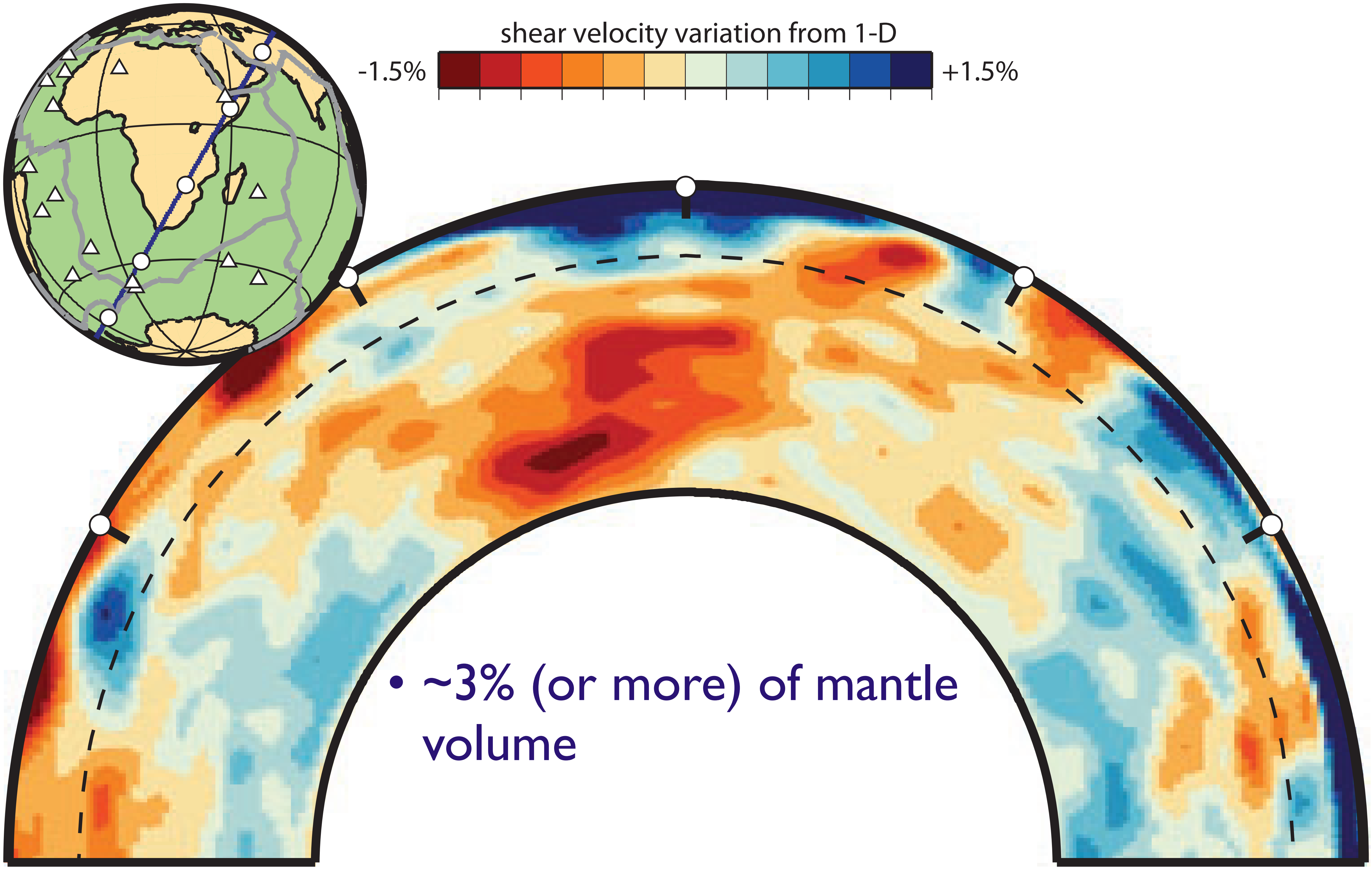
After Dziewoński, JGR, 1984

'Large Low-Shear Velocity Provinces'



Ritsema et al., GJI, 2010

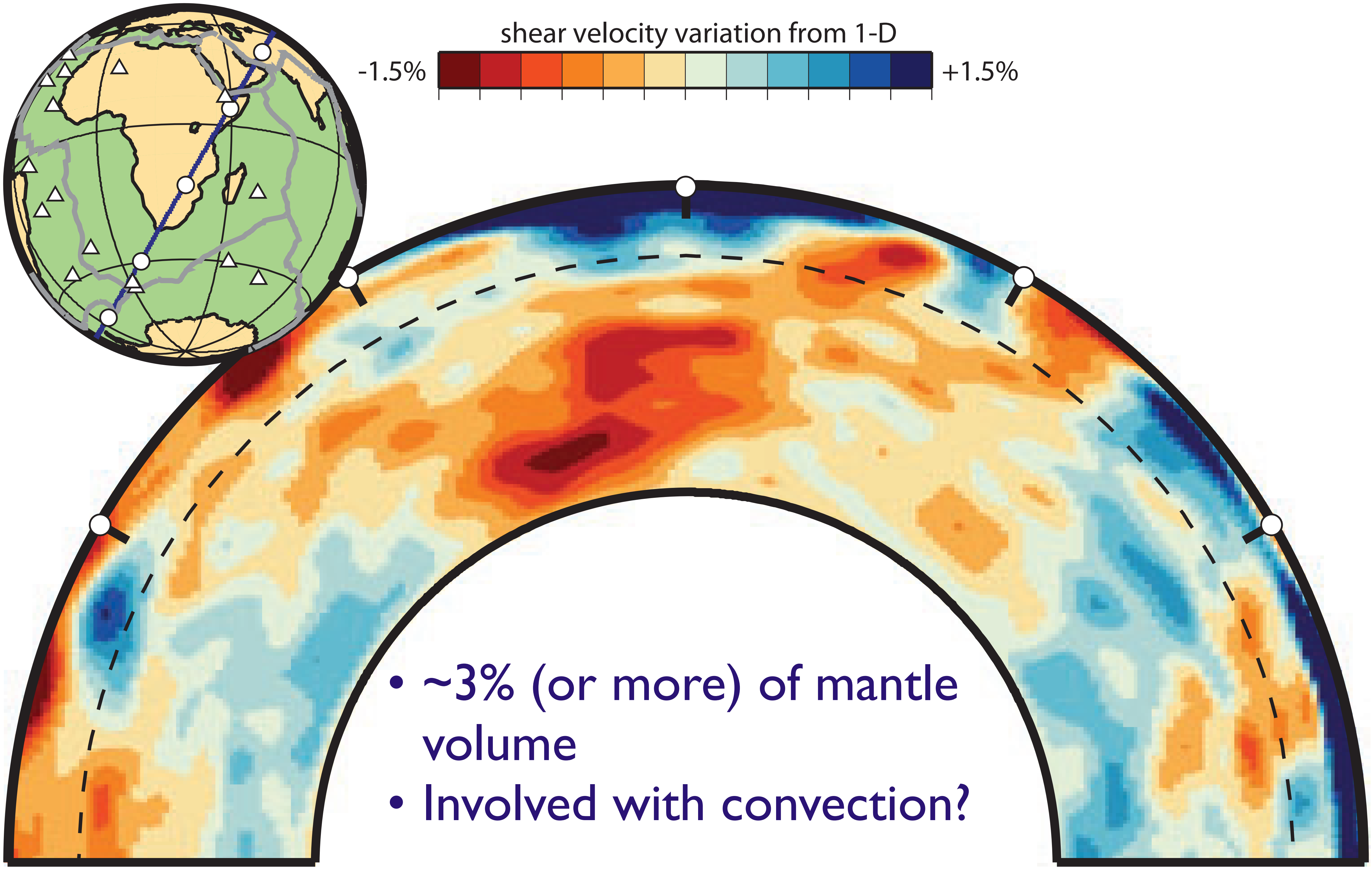
‘Large Low-Shear Velocity Provinces’



- ~3% (or more) of mantle volume

Ritsema et al., GJI, 2010

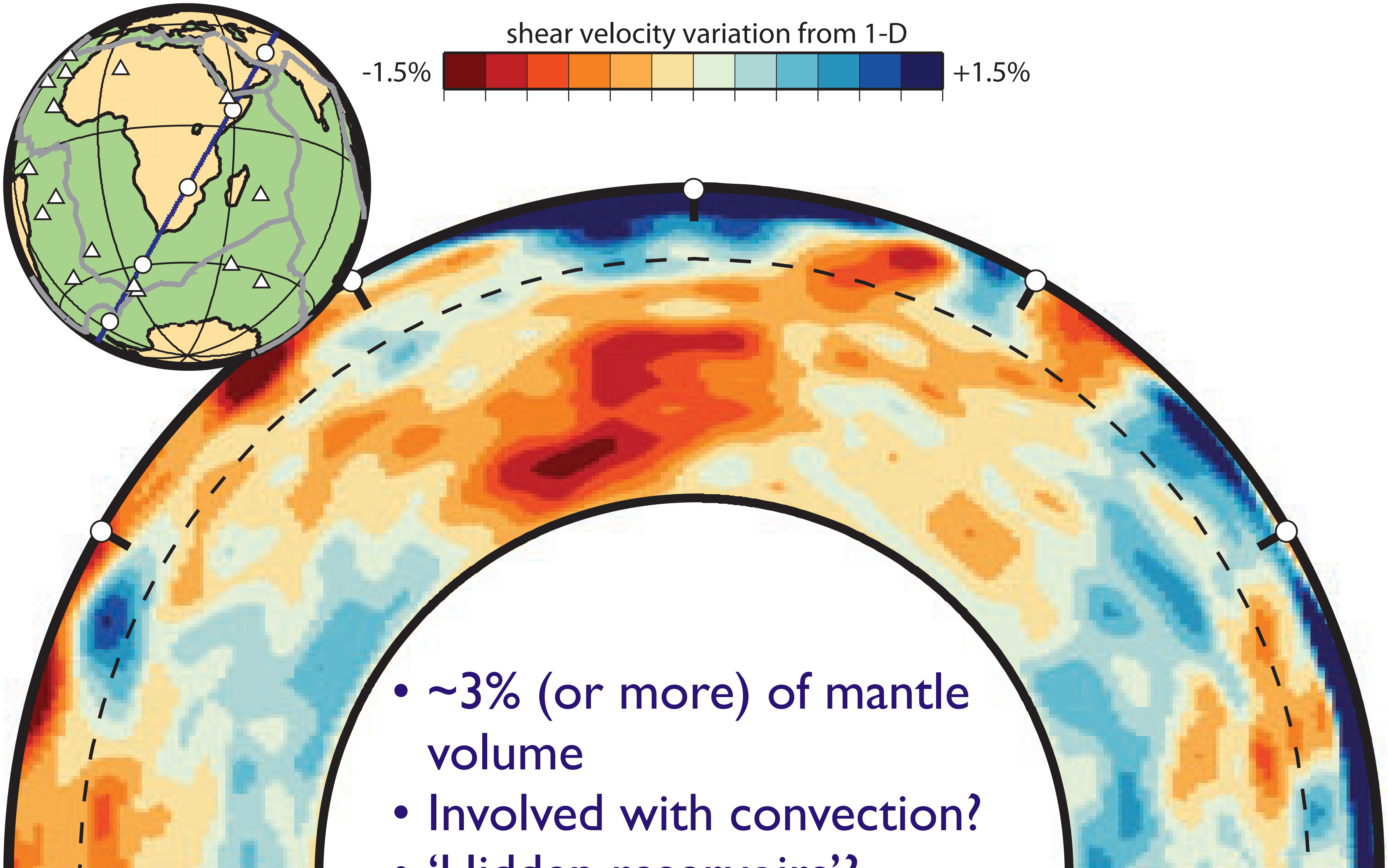
‘Large Low-Shear Velocity Provinces’



- ~3% (or more) of mantle volume
- Involved with convection?

Ritsema et al., GJI, 2010

‘**L**arge **L**ow-**S**hear **V**elocity **P**rovinces’



- ~3% (or more) of mantle volume
- Involved with convection?
- ‘Hidden reservoirs’?

Ritsema et al., GJI, 2010

Thermal *v.* thermochemical

Density

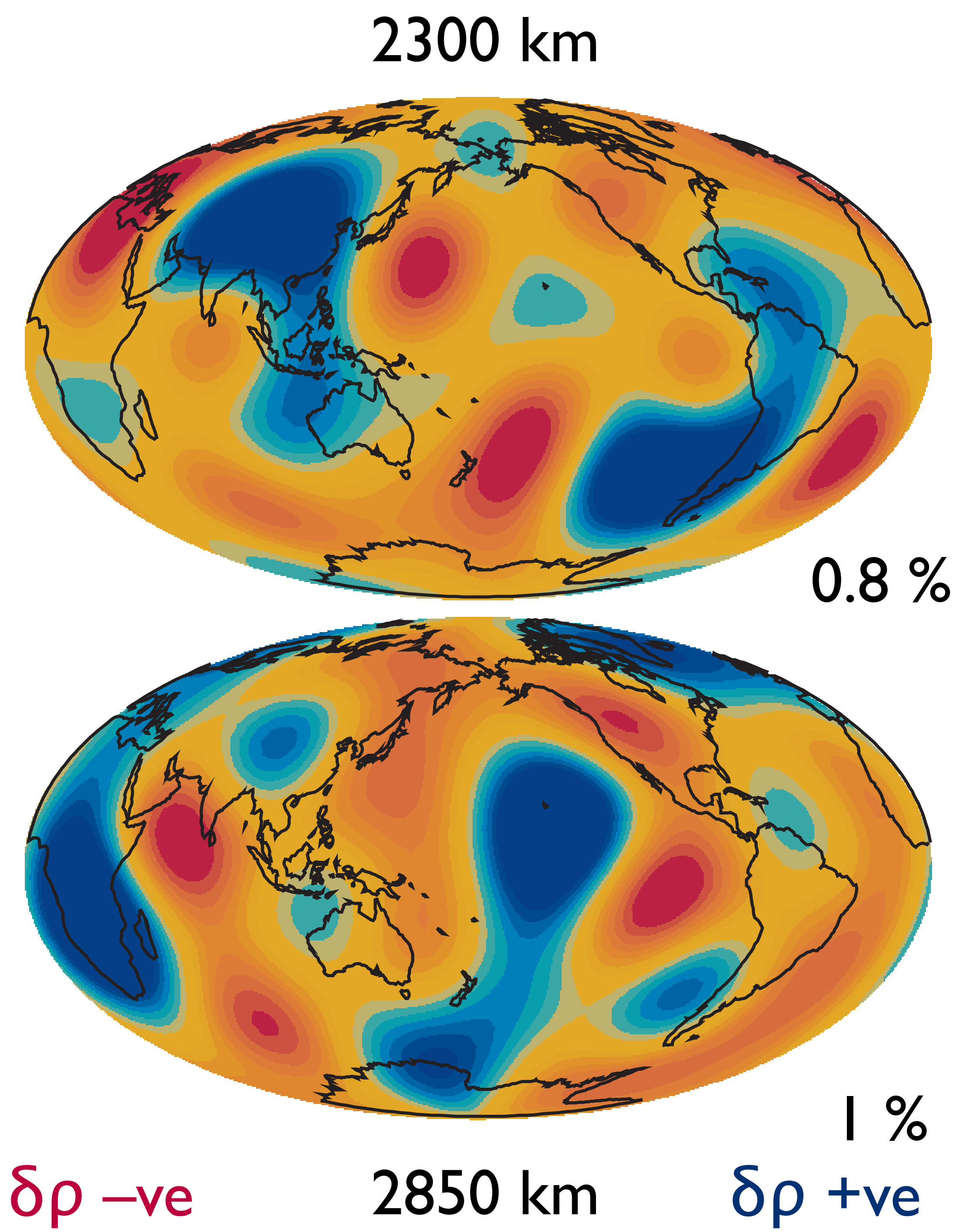
Bulk sound velocity

Ishii & Tromp, Science, 1998; Masters et al., Geophysical Monograph, 2000

Thermal *v.* thermochemical

Density

Bulk sound velocity



Ishii & Tromp, Science, 1998; Masters et al., Geophysical Monograph, 2000

Thermal *v.* thermochemical

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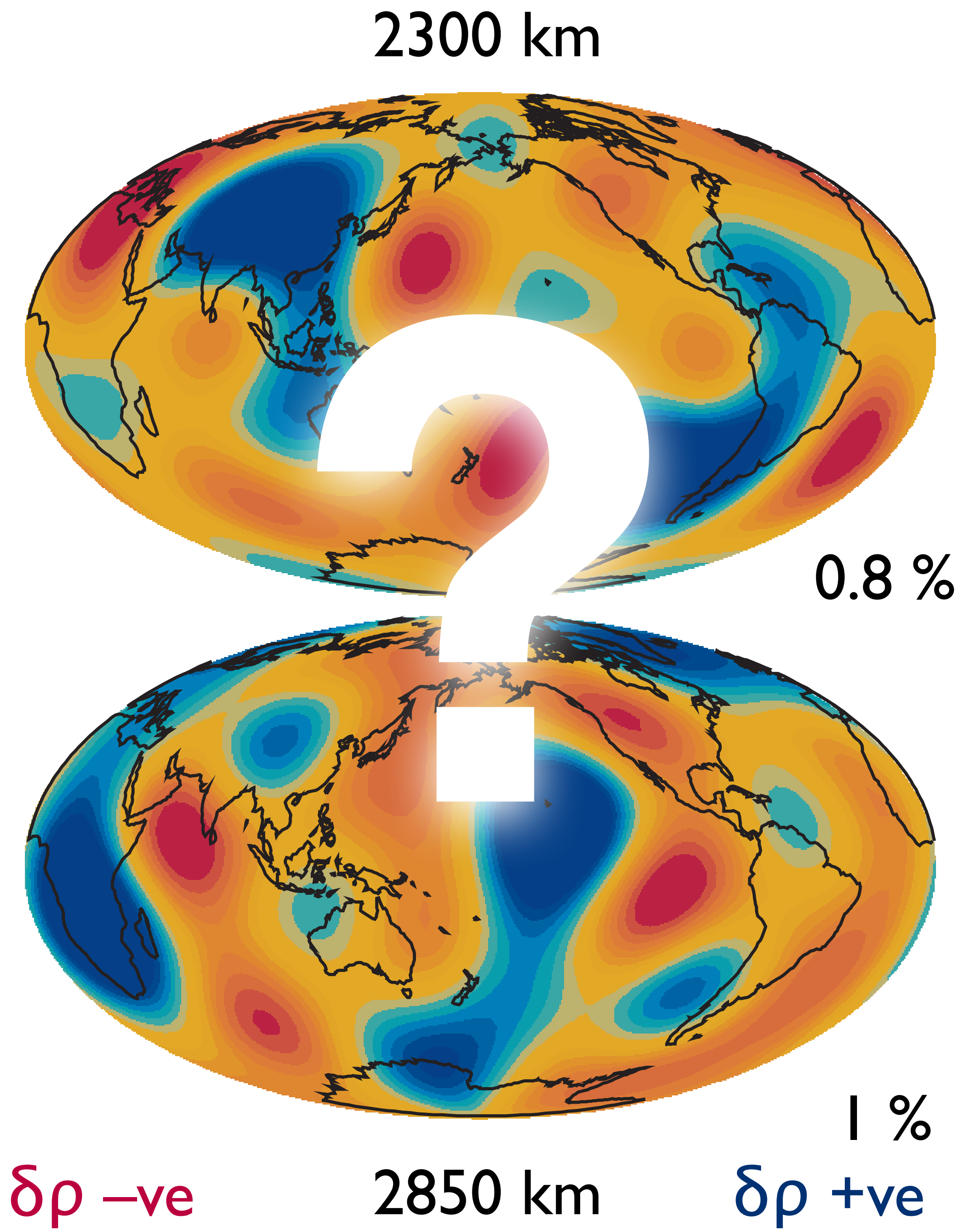


Ishii & Tromp, Science, 1998; Masters et al., Geophysical Monograph, 2000

Thermal *v.* thermochemical

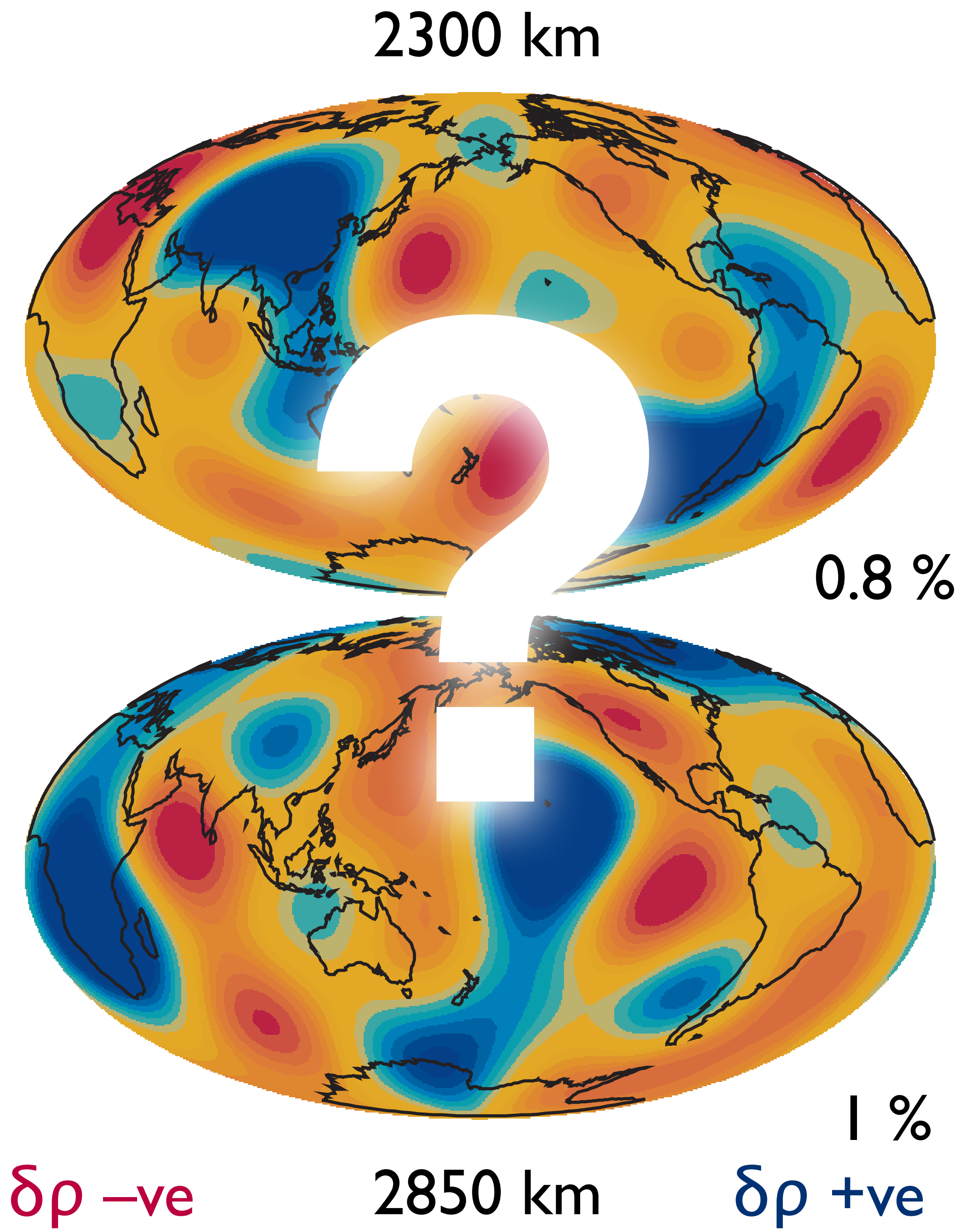
Density

Bulk sound velocity

$$V_{\mathrm{P}} = \sqrt{\frac{\frac{4}{3}\mu + K}{\rho}}$$

$$V_{\mathrm{S}} = \sqrt{\frac{\mu}{\rho}}$$

$$V_{\phi} = \sqrt{\frac{K}{\rho}}$$

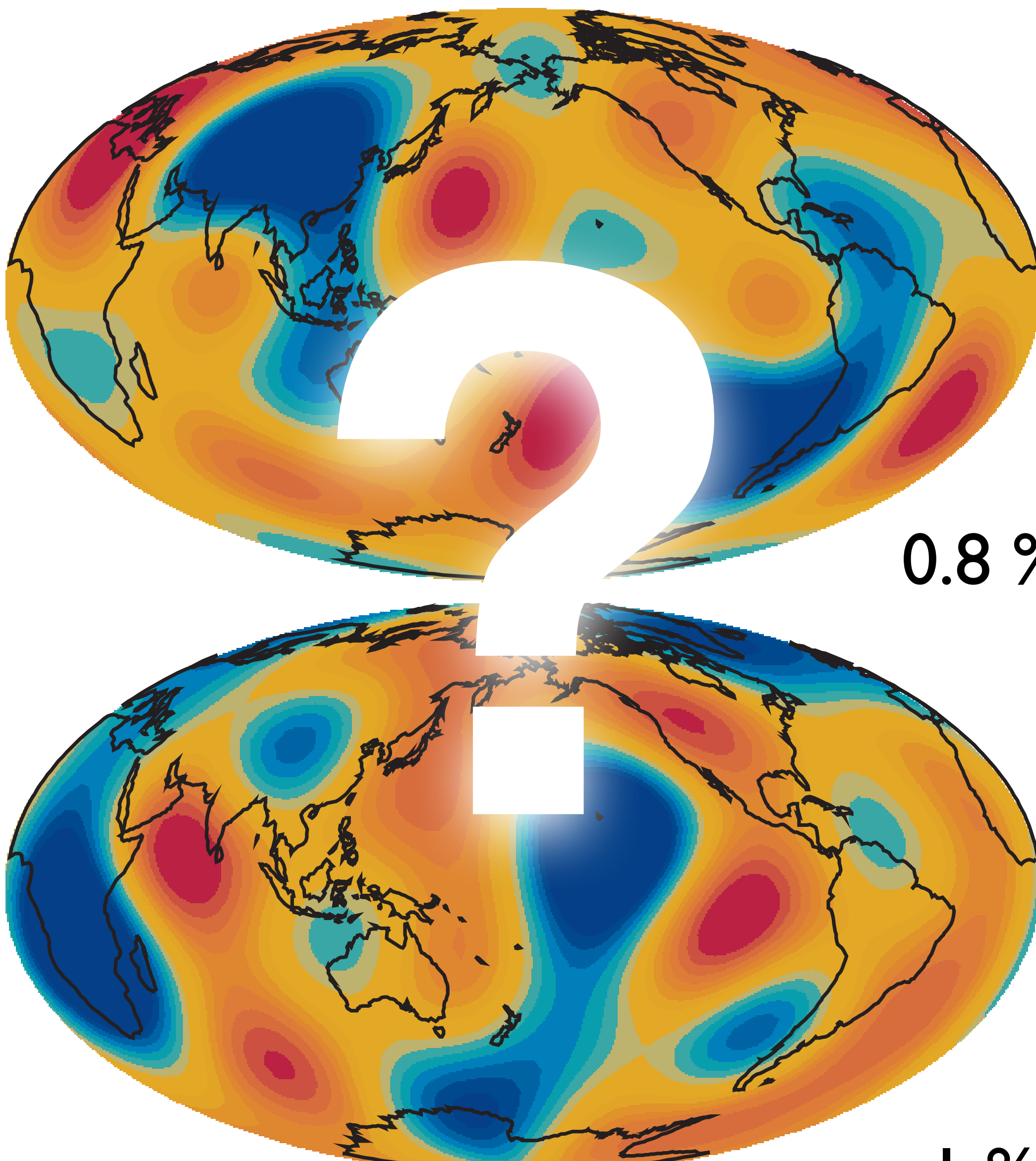


Ishii & Tromp, Science, 1998; Masters et al., Geophysical Monograph, 2000

Thermal *v.* thermochemical

Density

2300 km



0.8 %

1 %

$\delta\rho$ –ve   2850 km $\delta\rho$ +ve

Bulk sound velocity

$$V_{\mathrm{P}} = \sqrt{\frac{\frac{4}{3}\mu + K}{\rho}}$$

$$V_{\mathrm{S}} = \sqrt{\frac{\mu}{\rho}}$$

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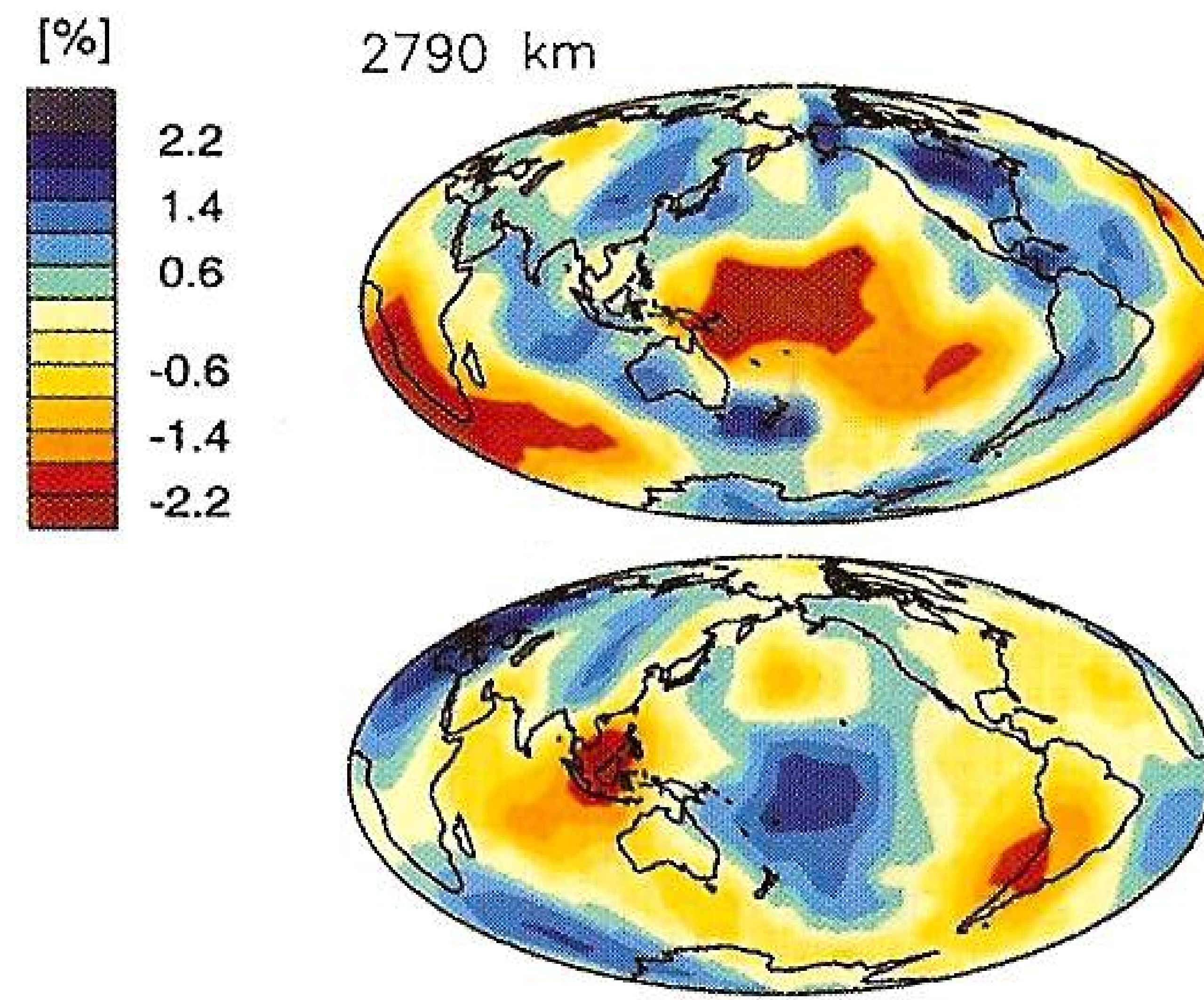


V_{S}

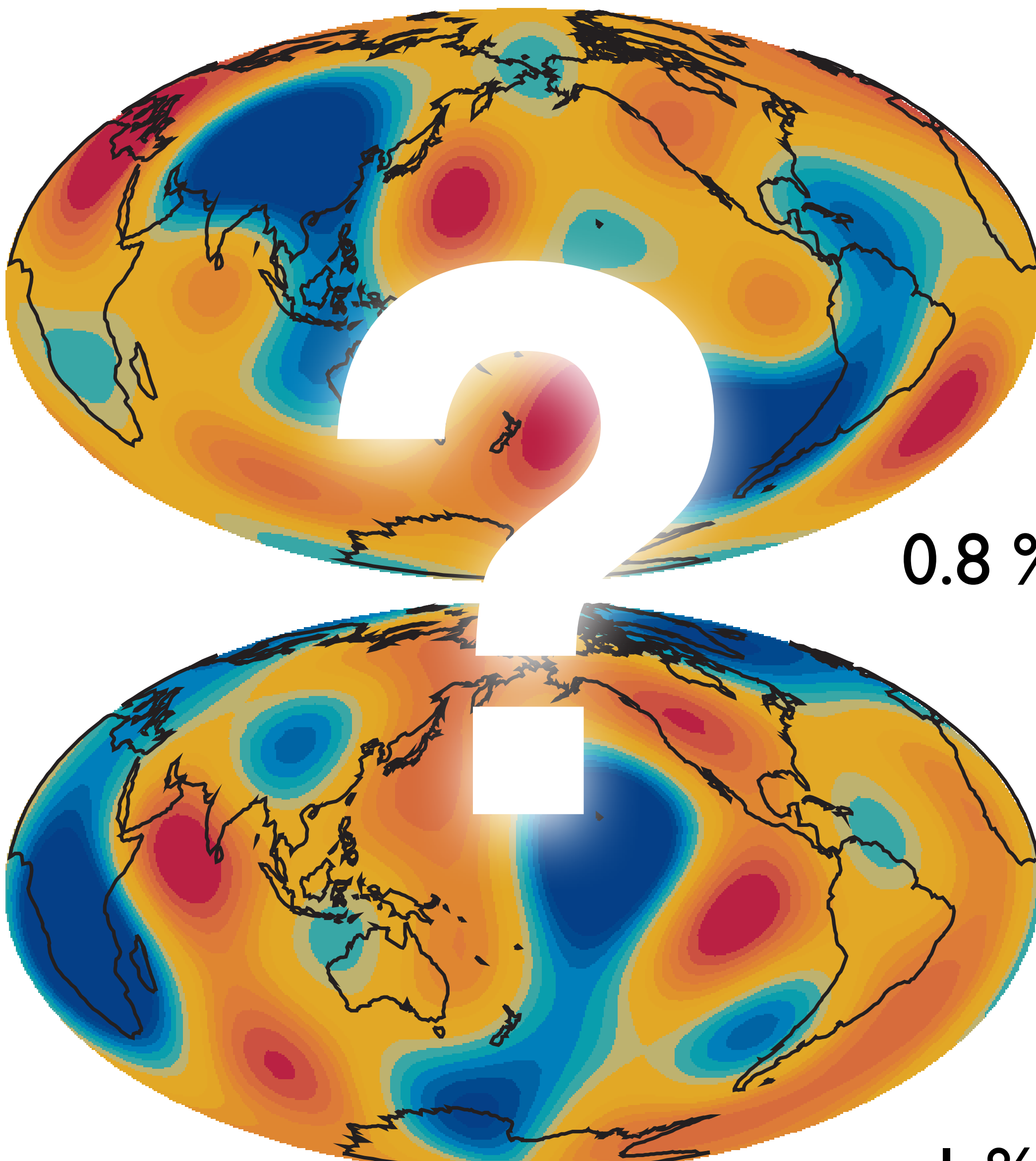
V_{ϕ}

Ishii & Tromp, Science, 1998; Masters et al., Geophysical Monograph, 2000

Thermal *v.* thermochemical

Density

2300 km



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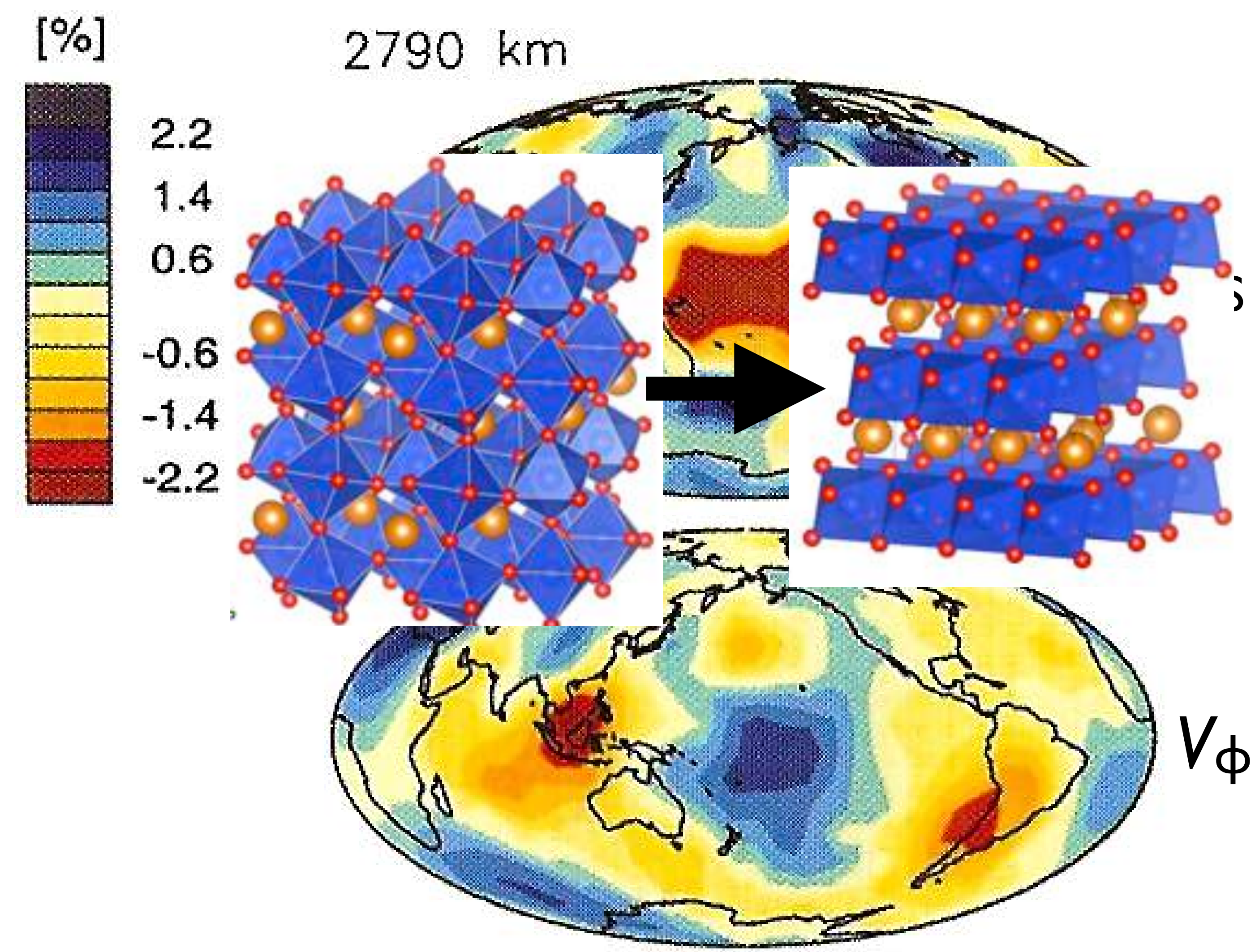

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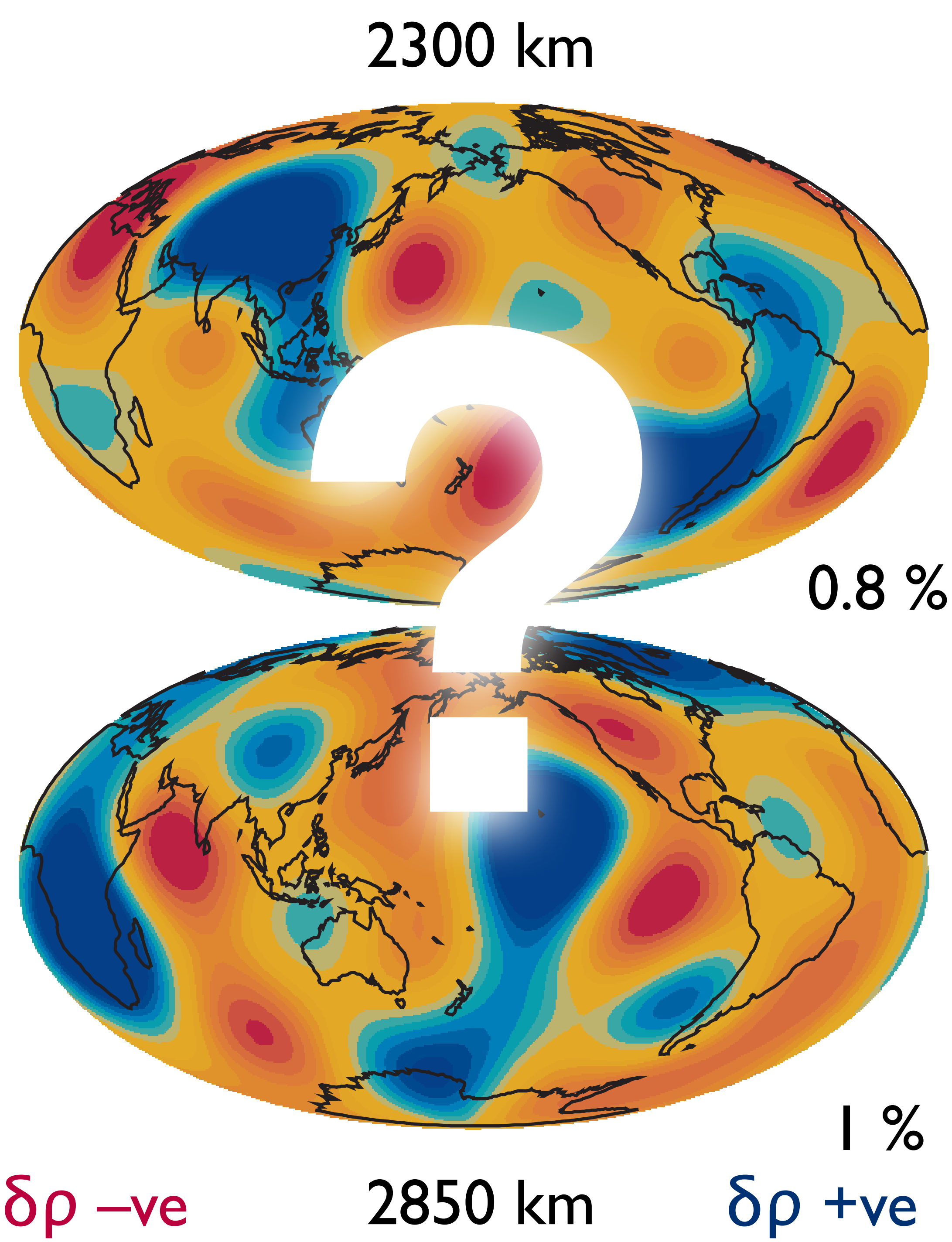
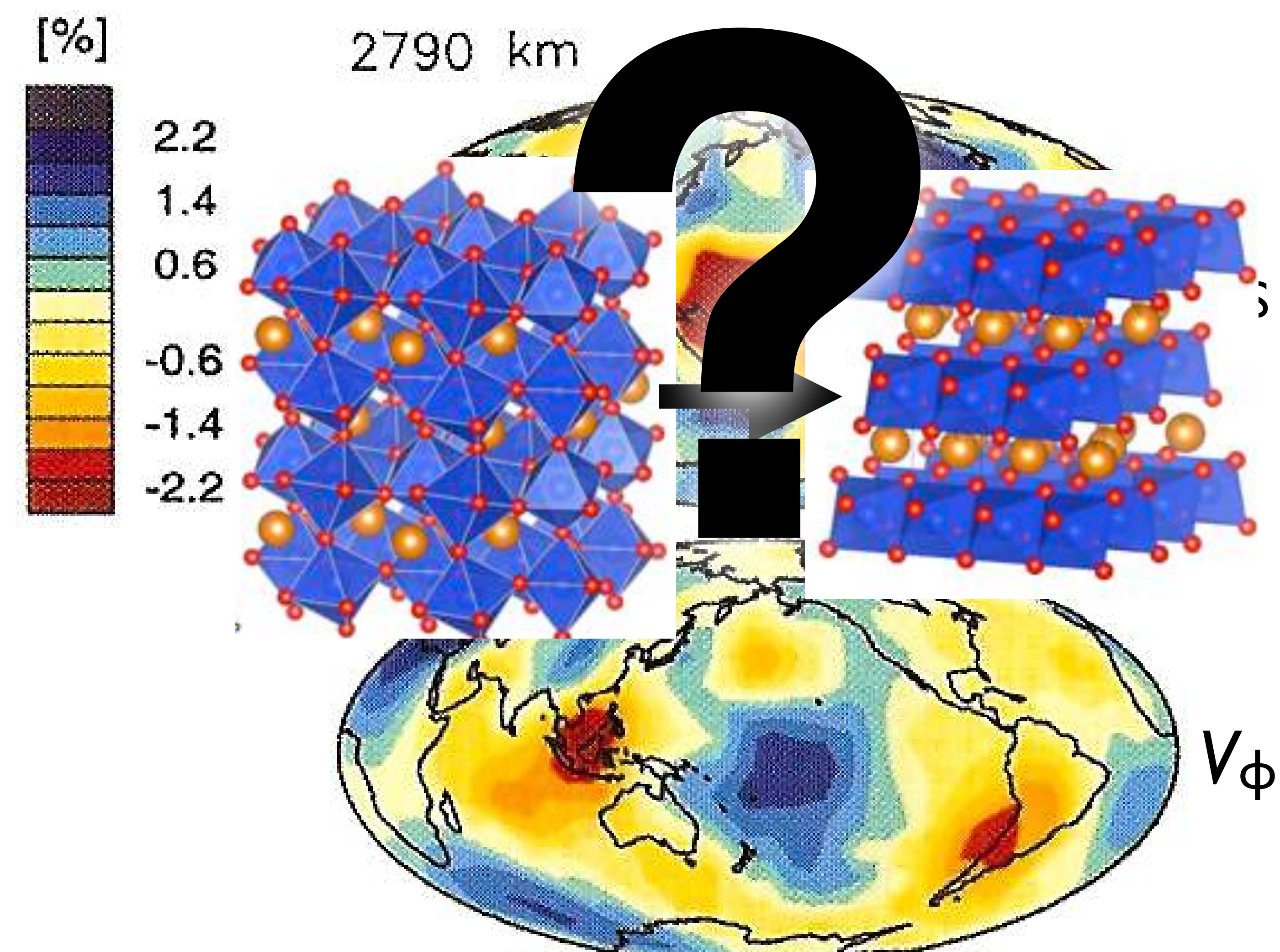
Thermal *v.* thermochemical

Density



Bulk sound velocity

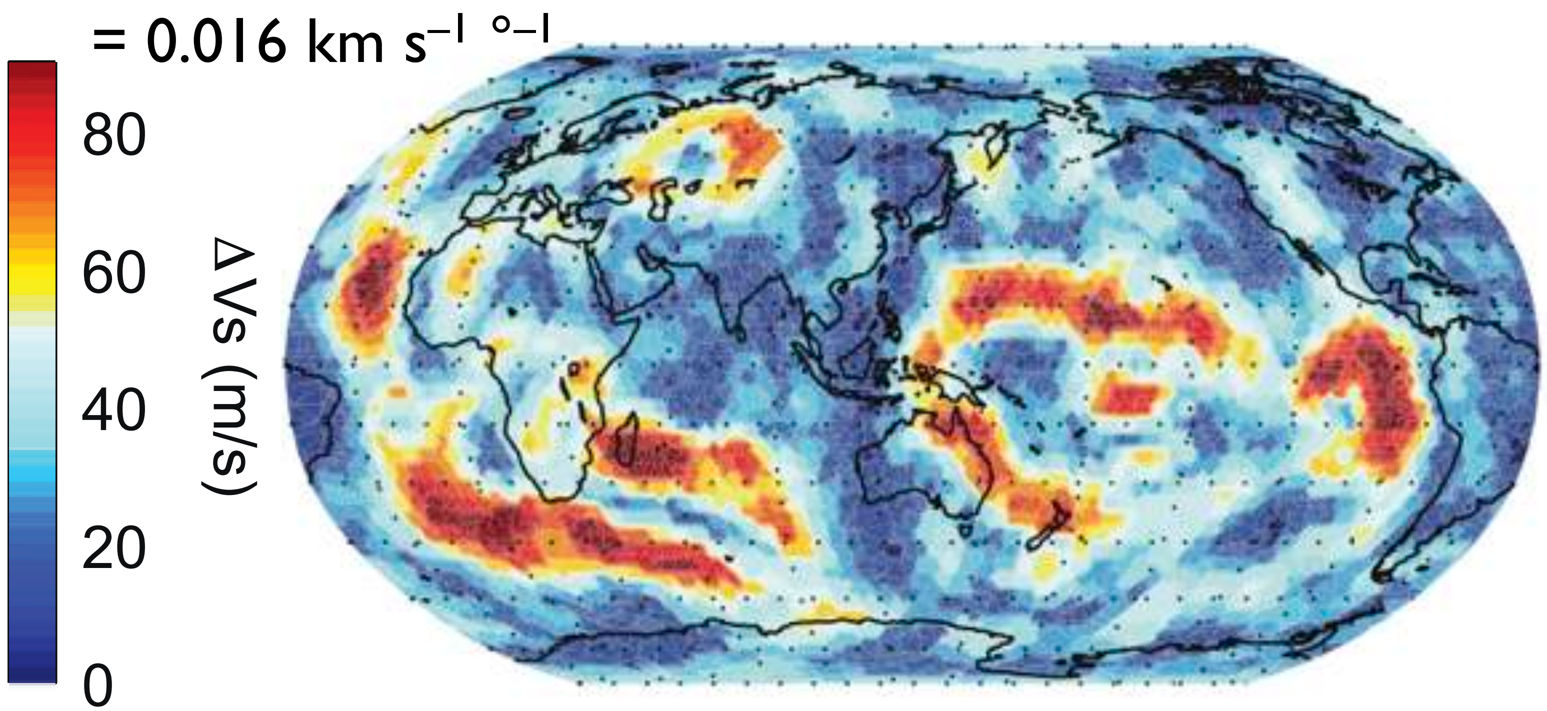
$$V_{\mathrm{P}} = \sqrt{\frac{\frac{4}{3}\mu + K}{\rho}} \qquad V_{\mathrm{S}} = \sqrt{\frac{\mu}{\rho}} \qquad V_{\phi} = \sqrt{\frac{K}{\rho}}$$

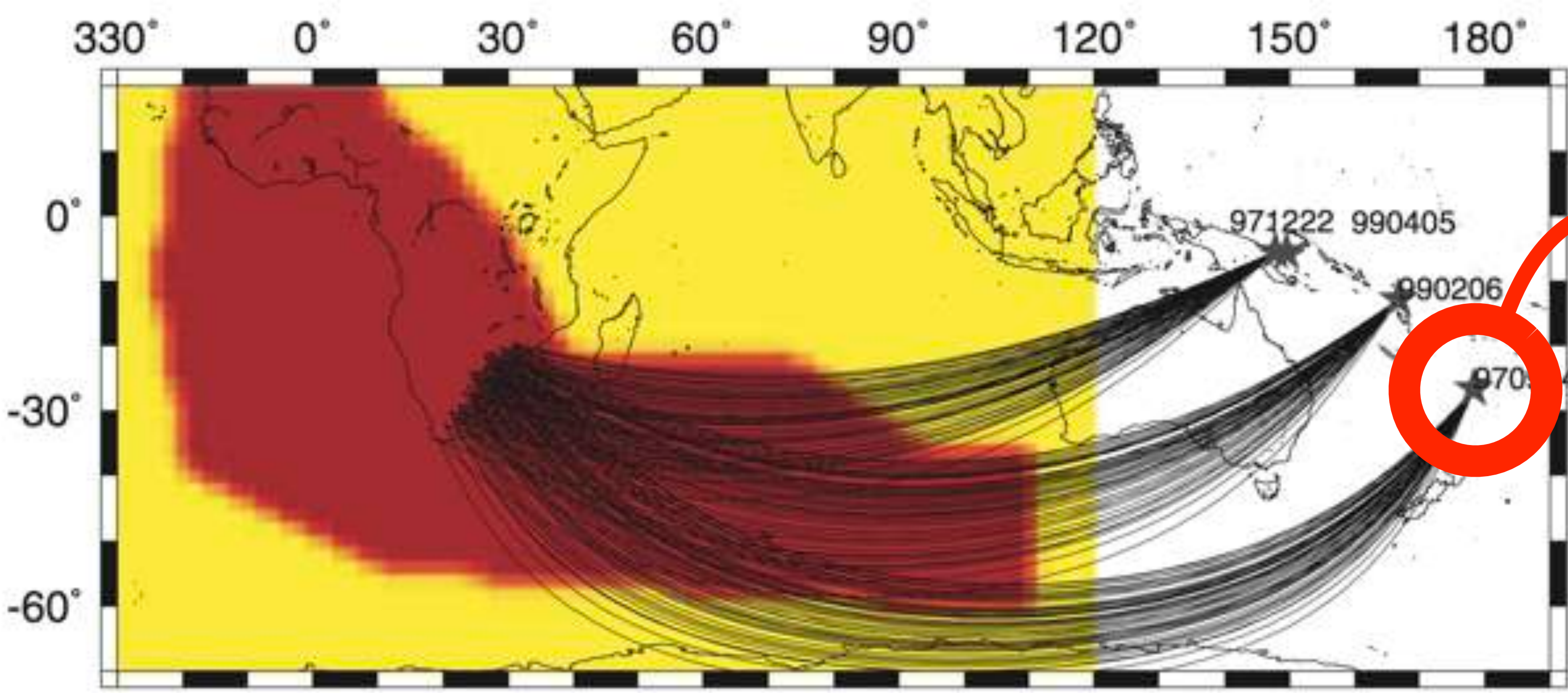


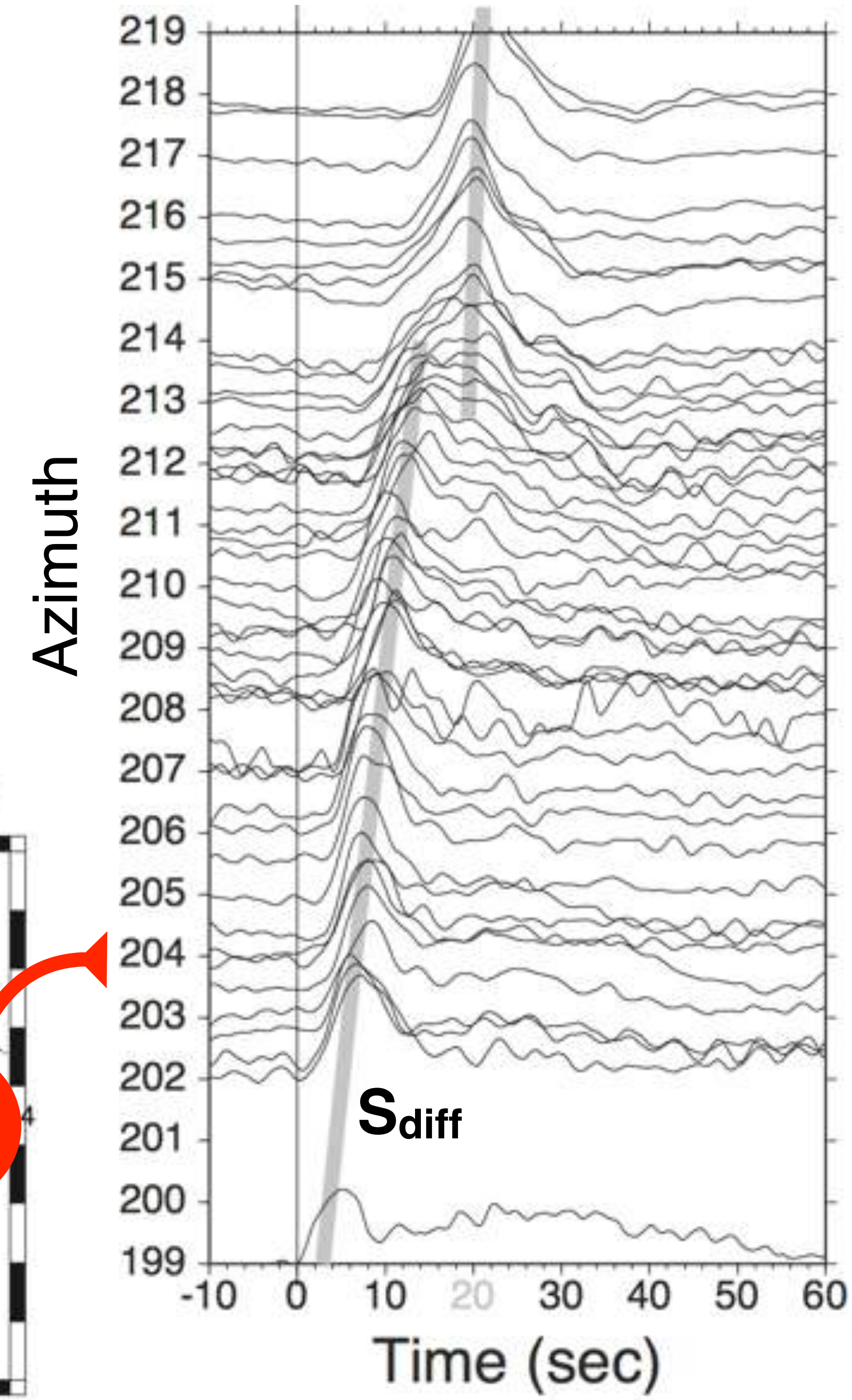
Ishii & Tromp, Science, 1998; Masters et al., Geophysical Monograph, 2000

Thermal *v.* thermochemical

Lateral velocity gradients

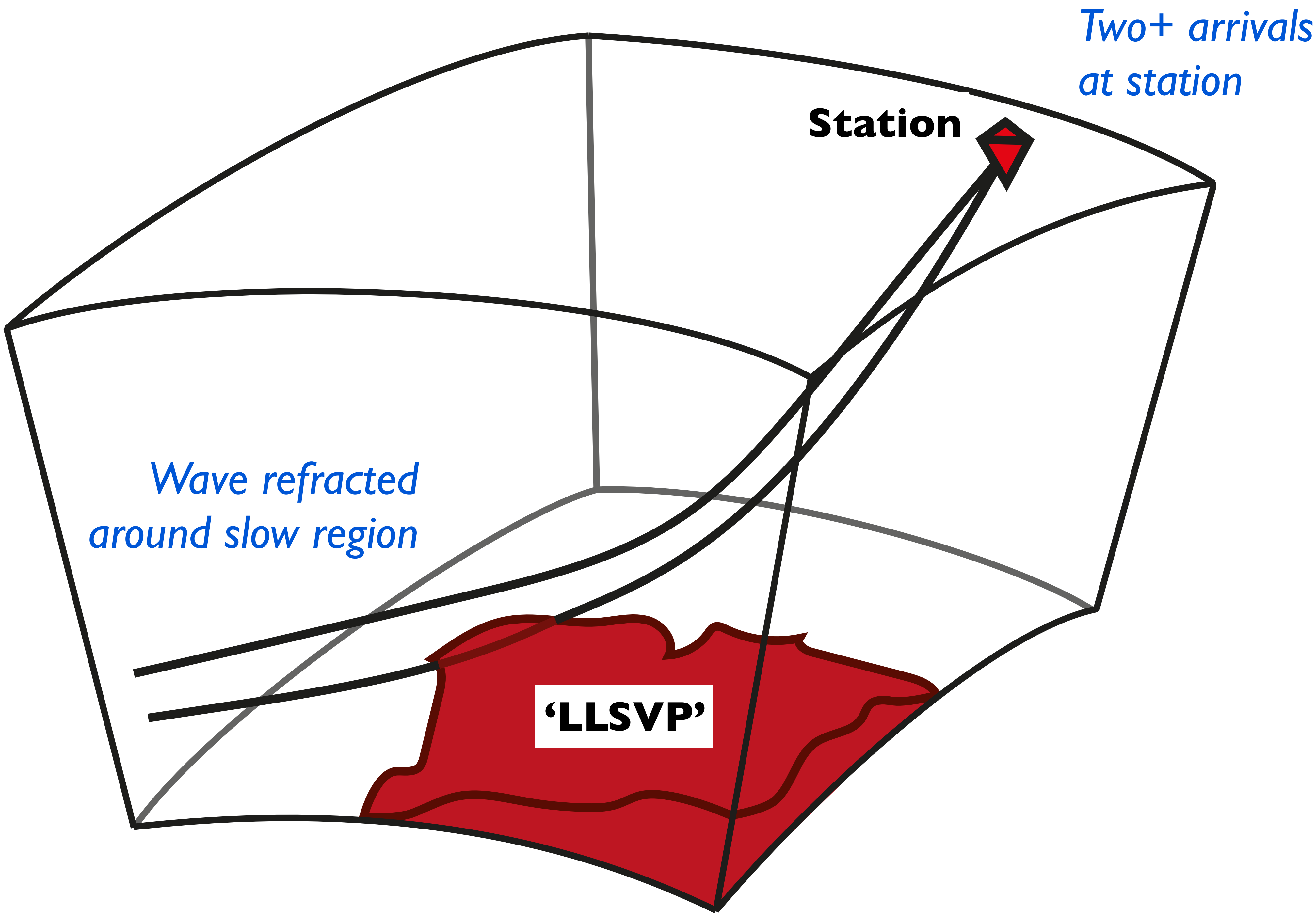




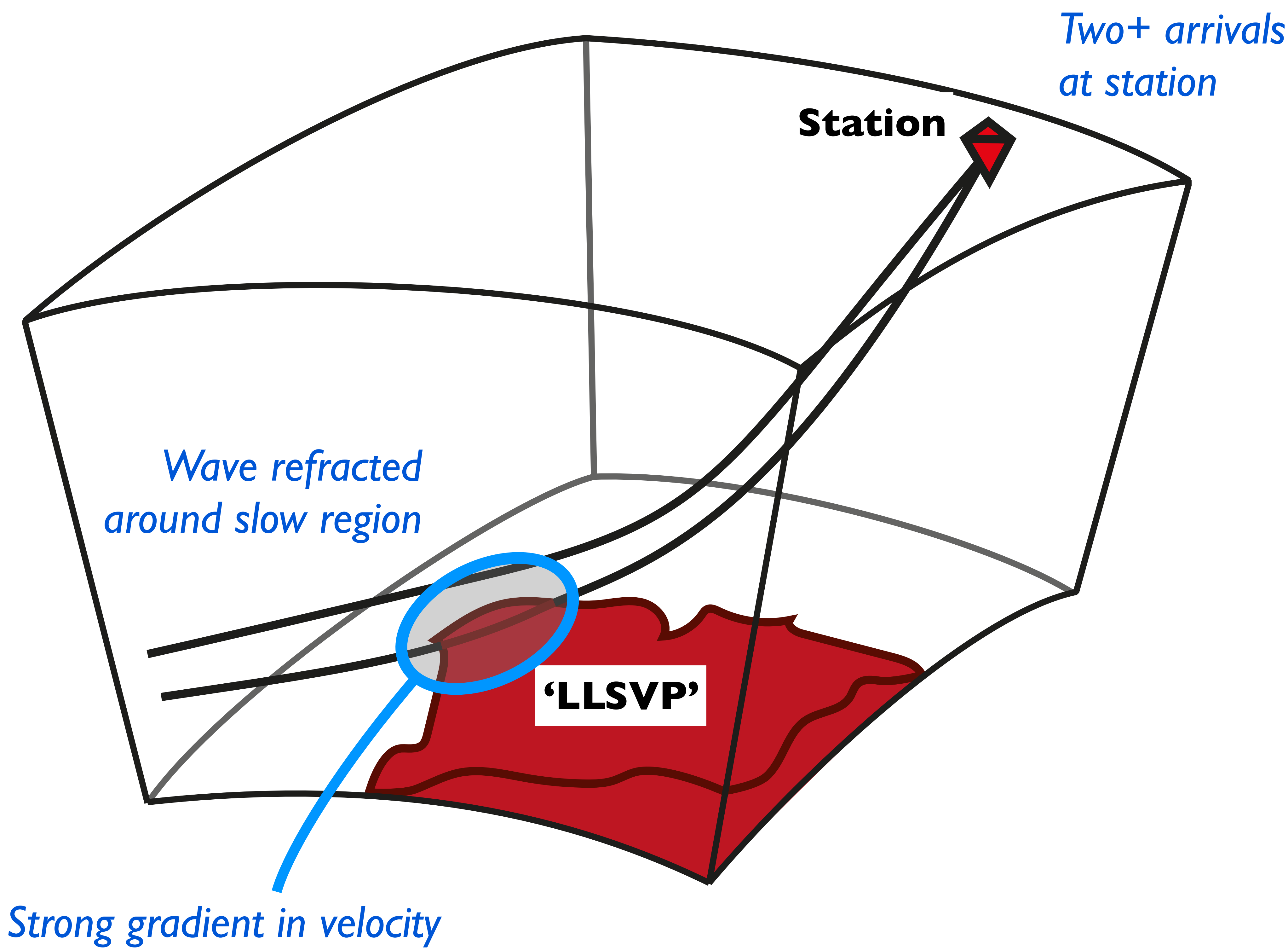


Lekić et al., 2012; Ni et al., 2005

‘Sharp sides’: multipathing



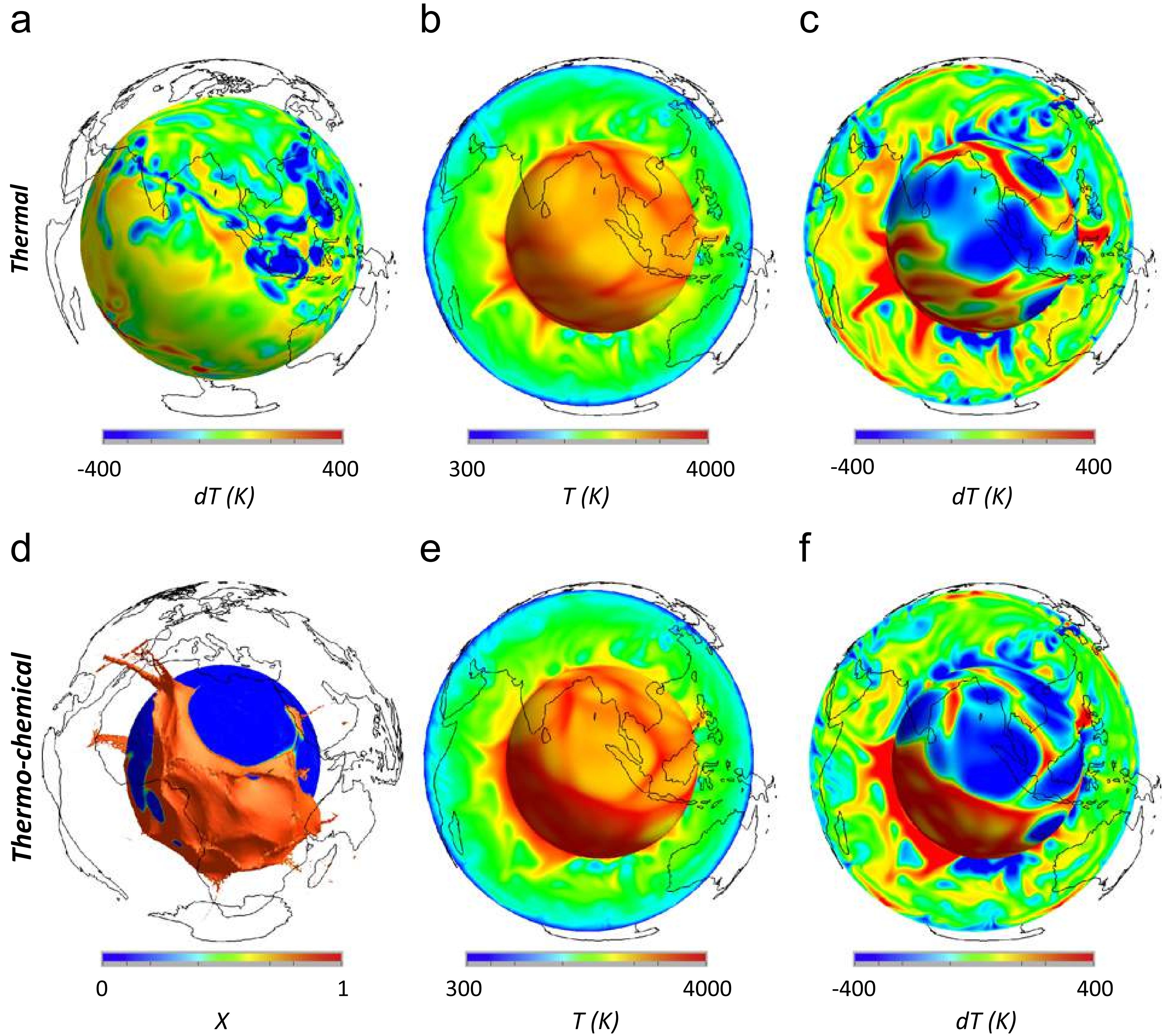
‘Sharp sides’: multipathing



Convection simulations

T

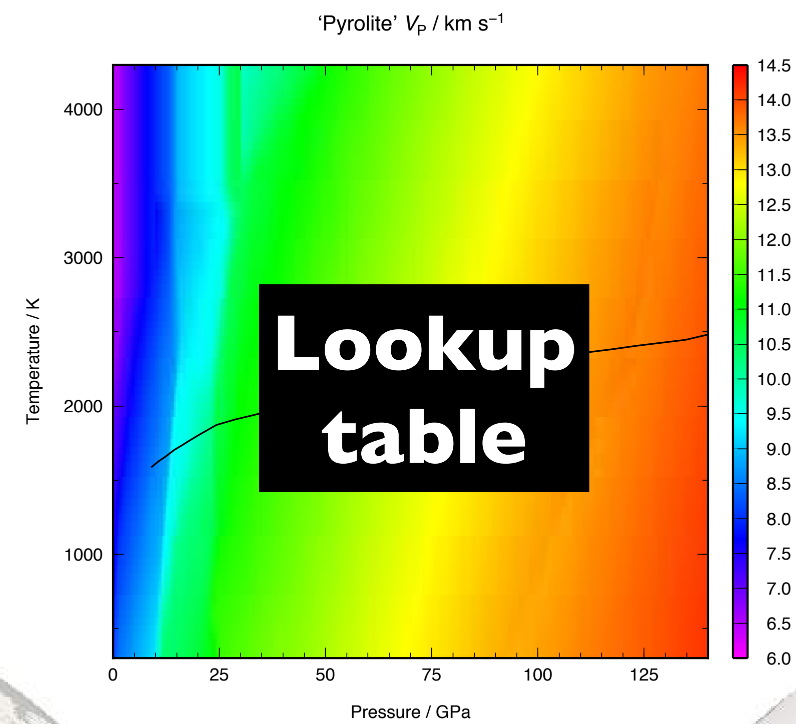
TC



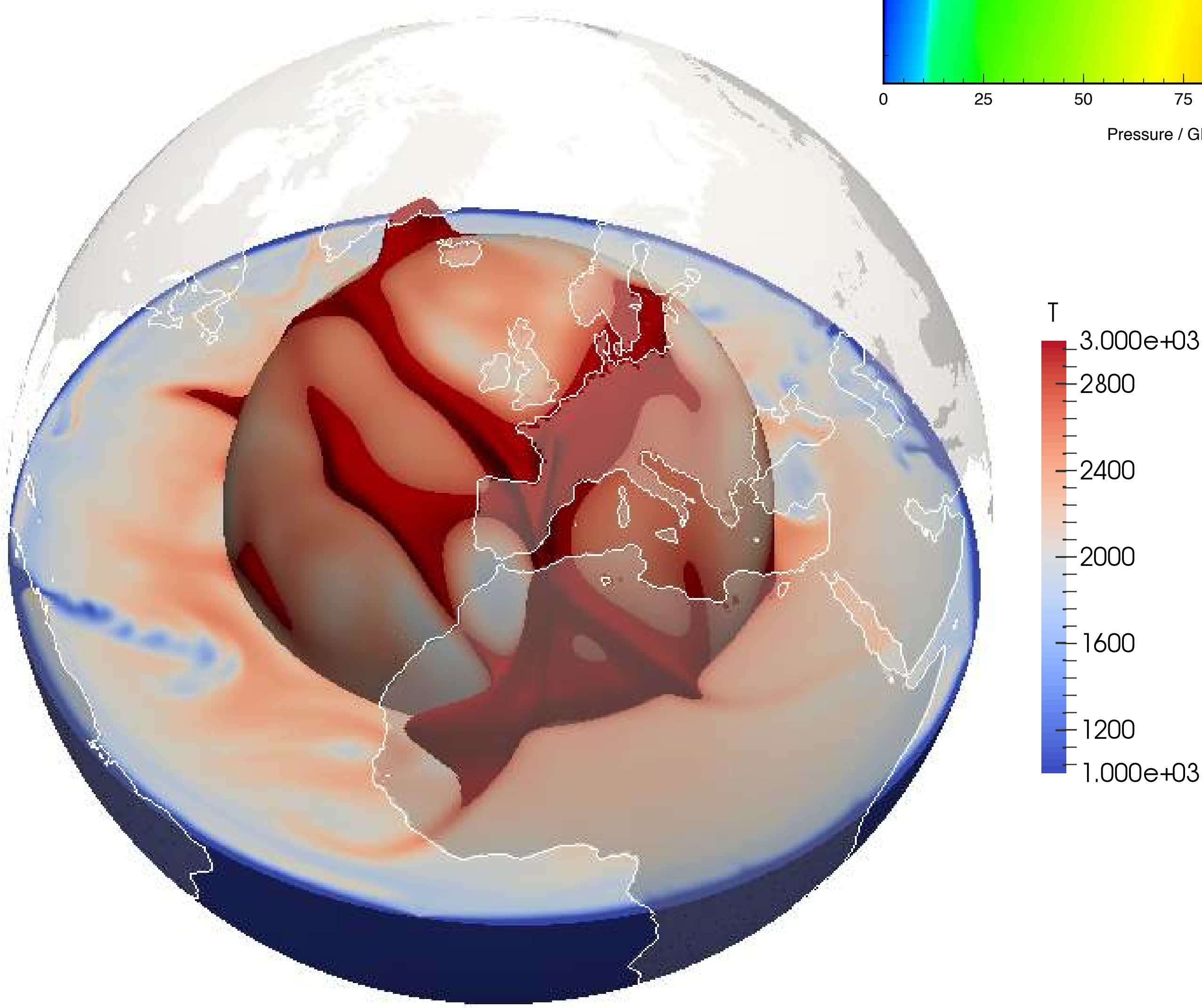
Davies et al., 2012

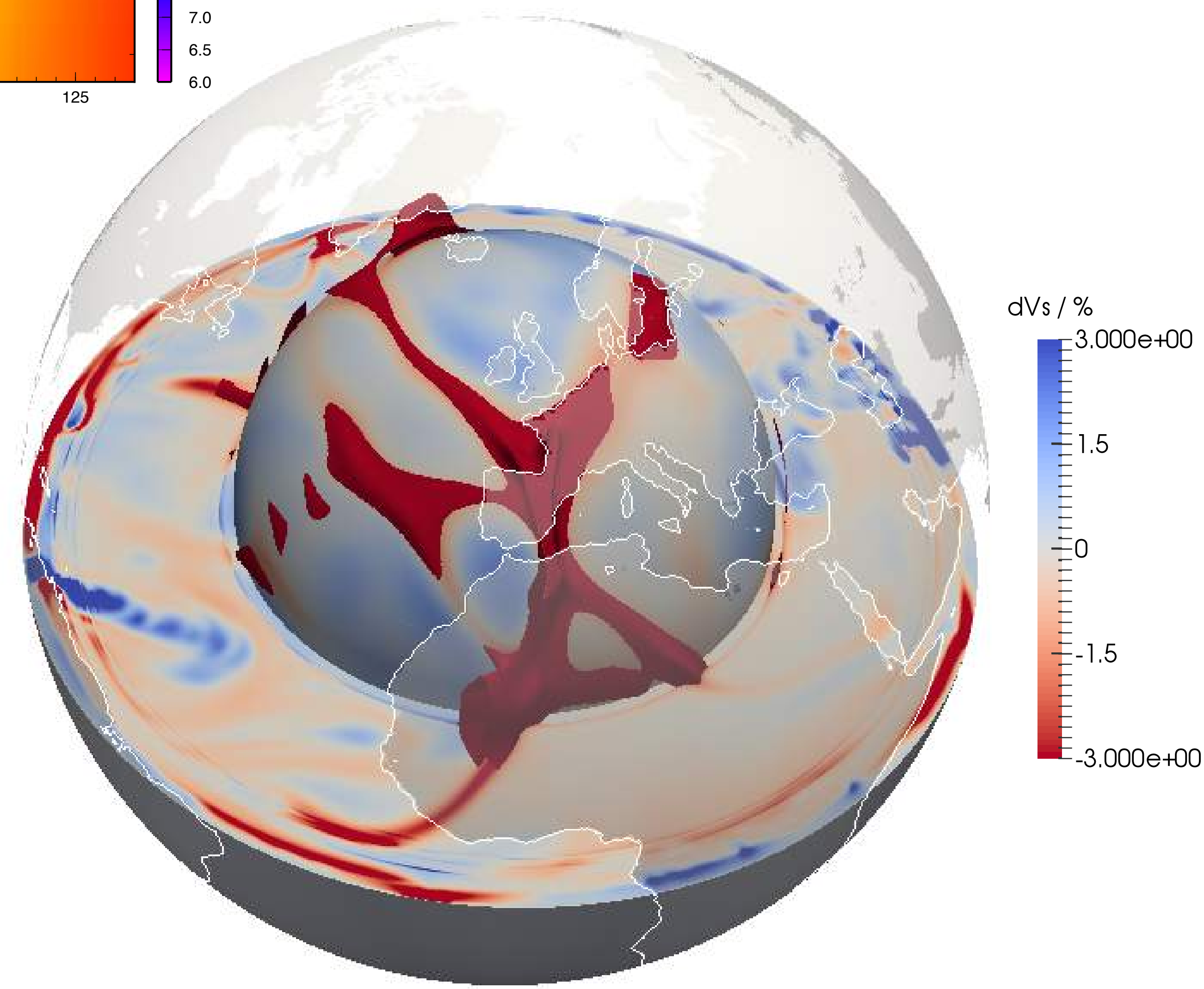
Conversion to seismic properties

T, P; C



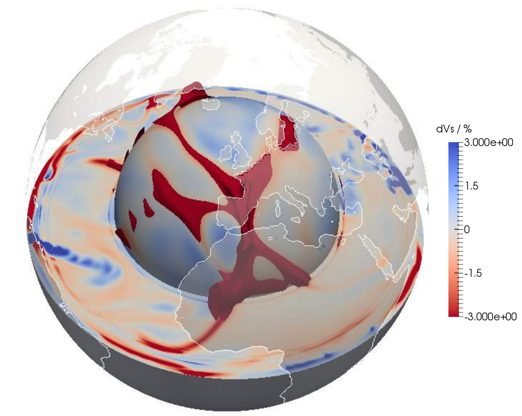
V_P, V_S, ρ, Q_μ





Stixrude & Lithgow-Bertelloni, 2005, 2011; Goes et al., 2004

Tomography



Data

↓

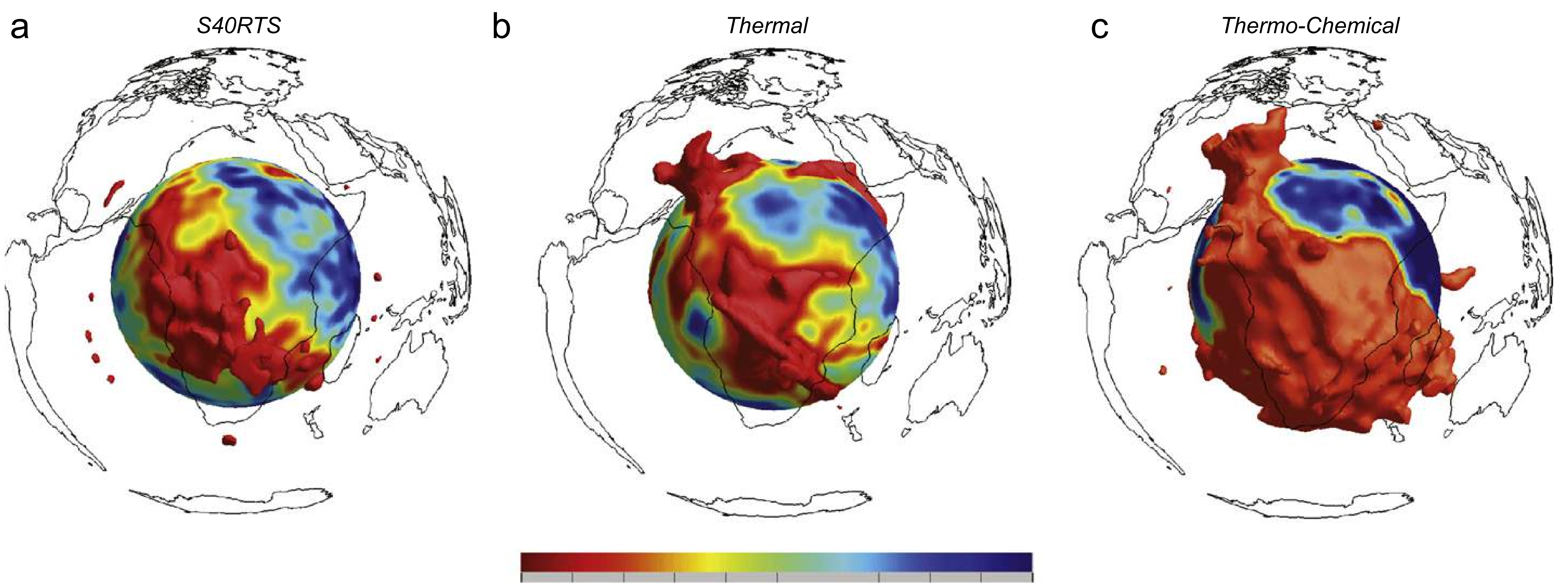
Inversion; damping

↓

Tomography

R: 'resolution operator'

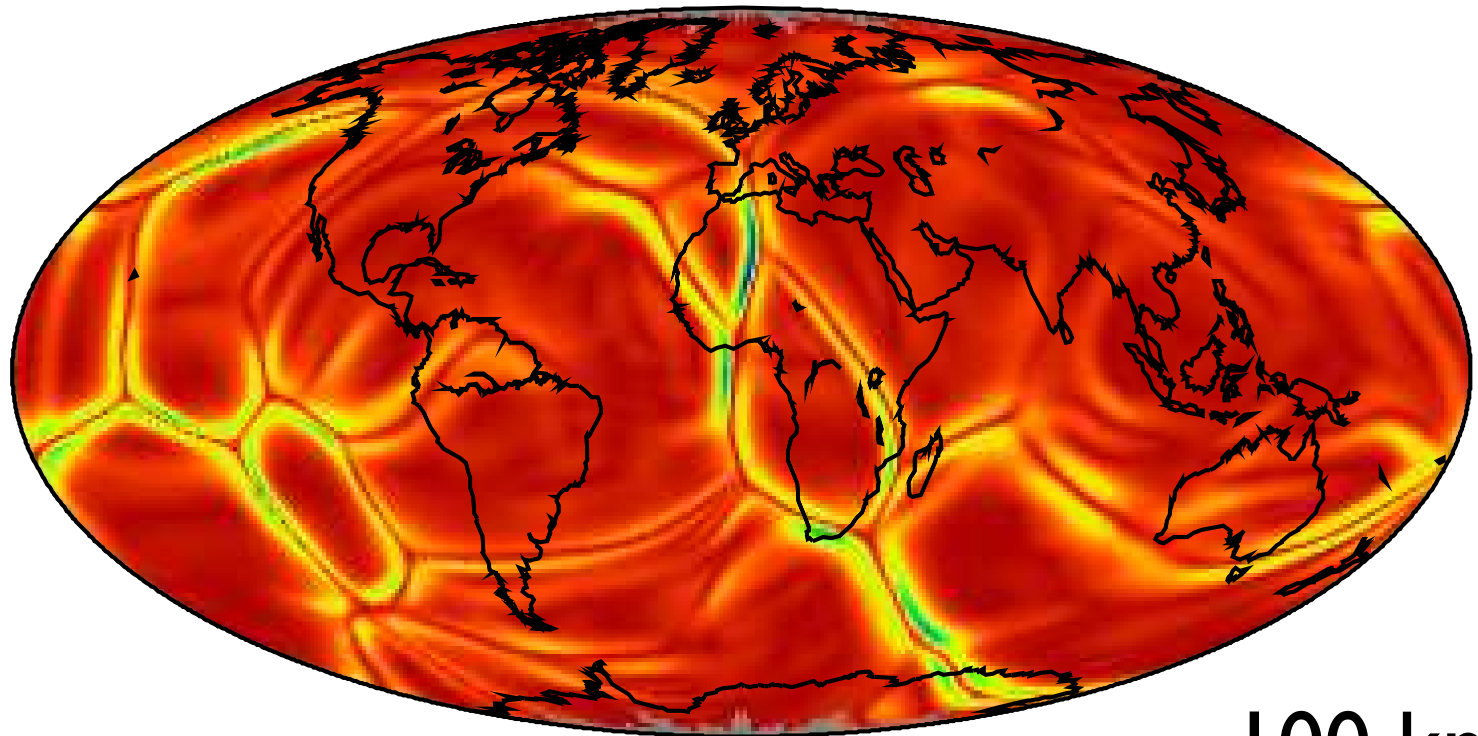
T **TC**



Davies et al., 2012

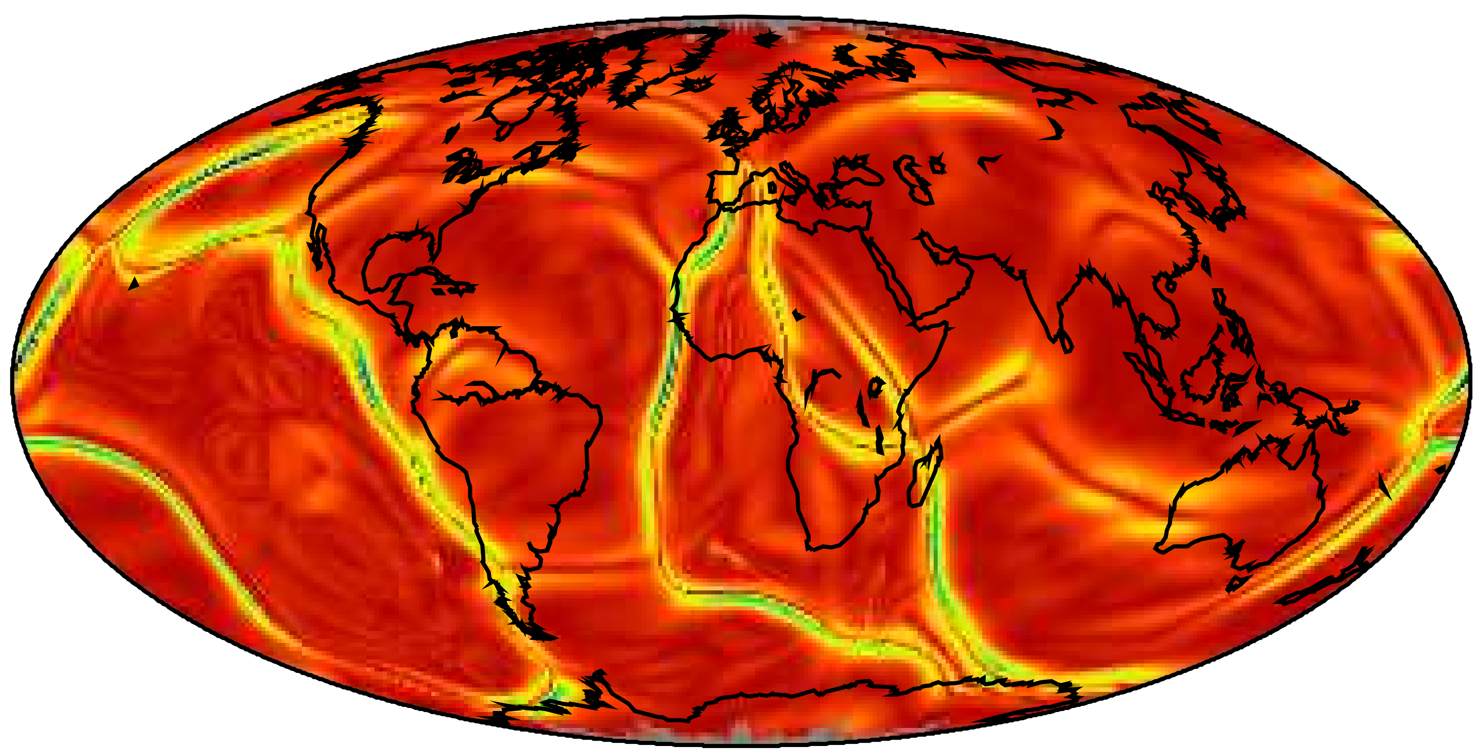
Lateral gradients: models

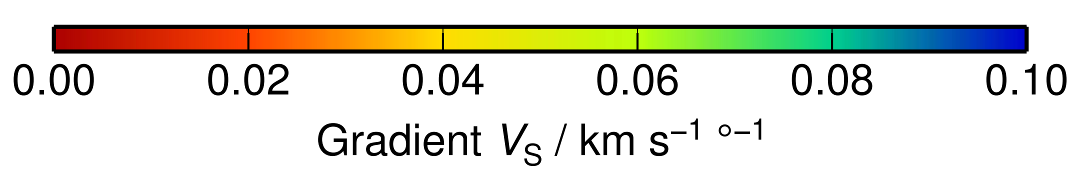
T



100 km above CMB

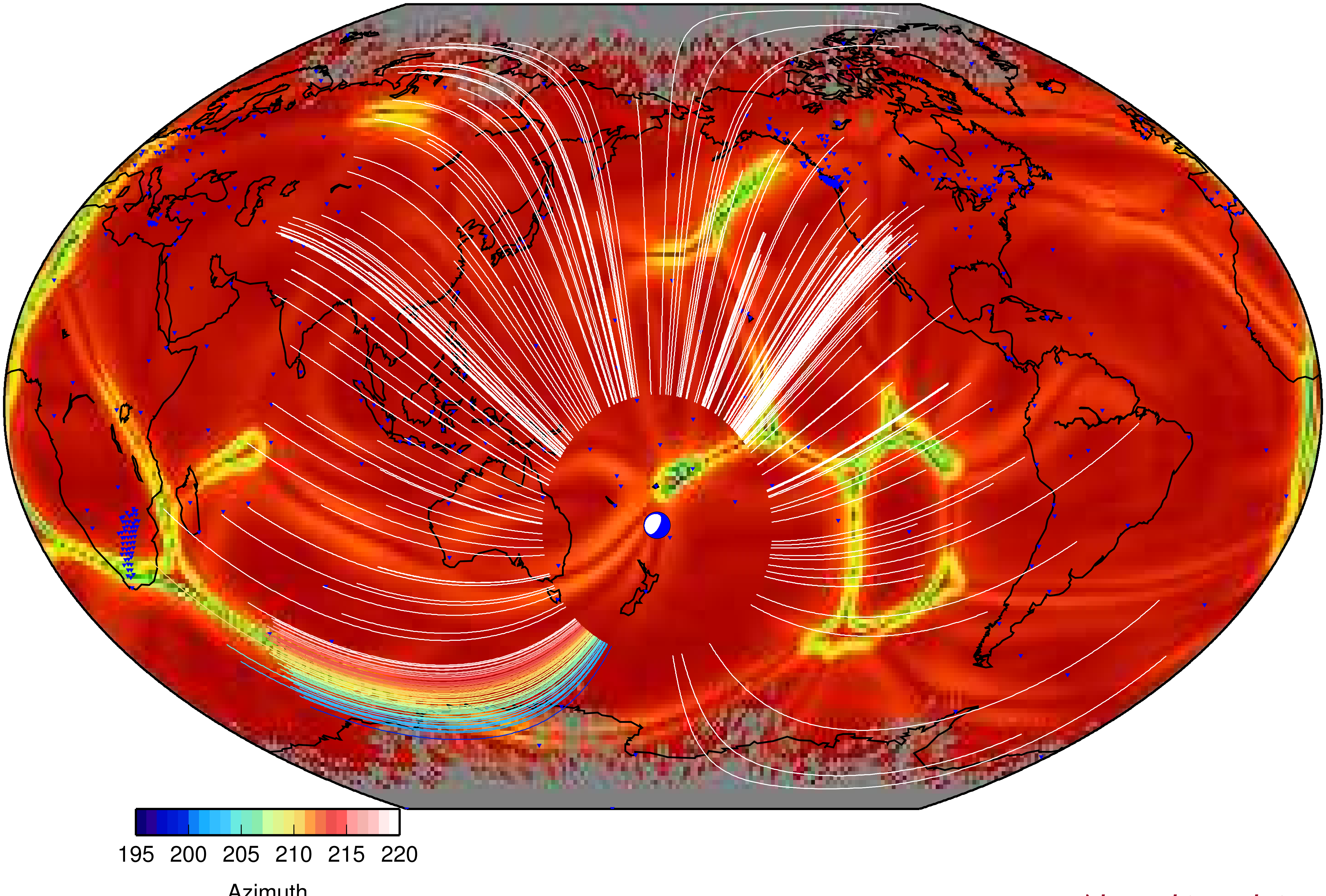
TC





Nowacki et al., in prep.

3D effect: seismic simulations



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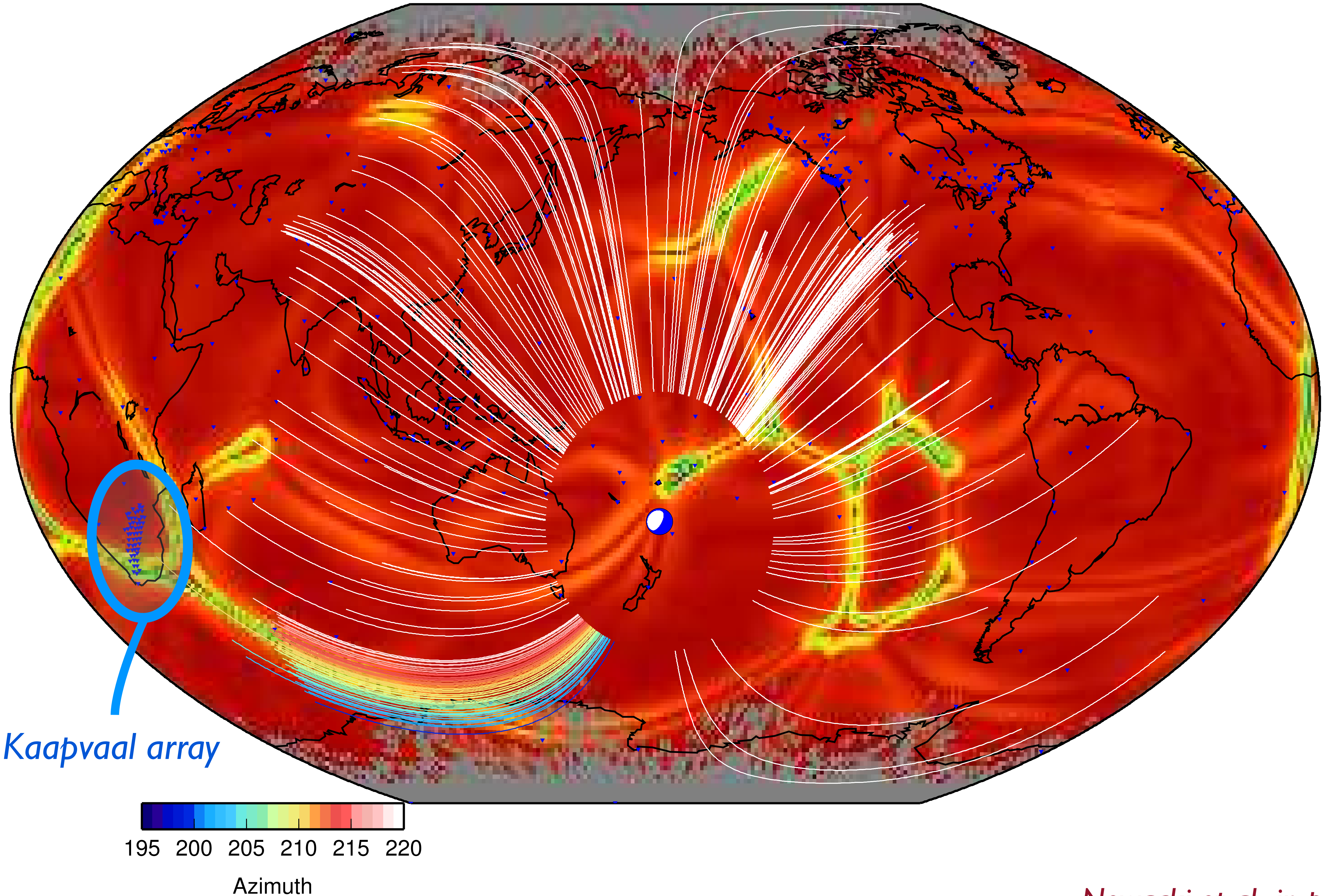
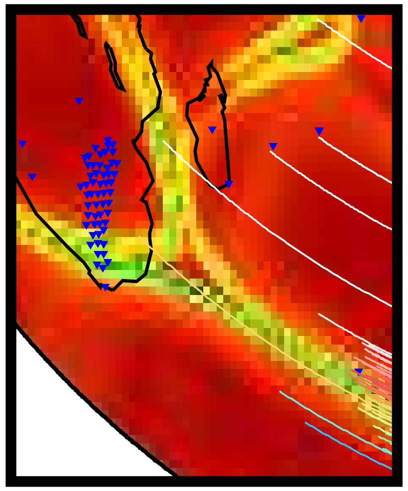
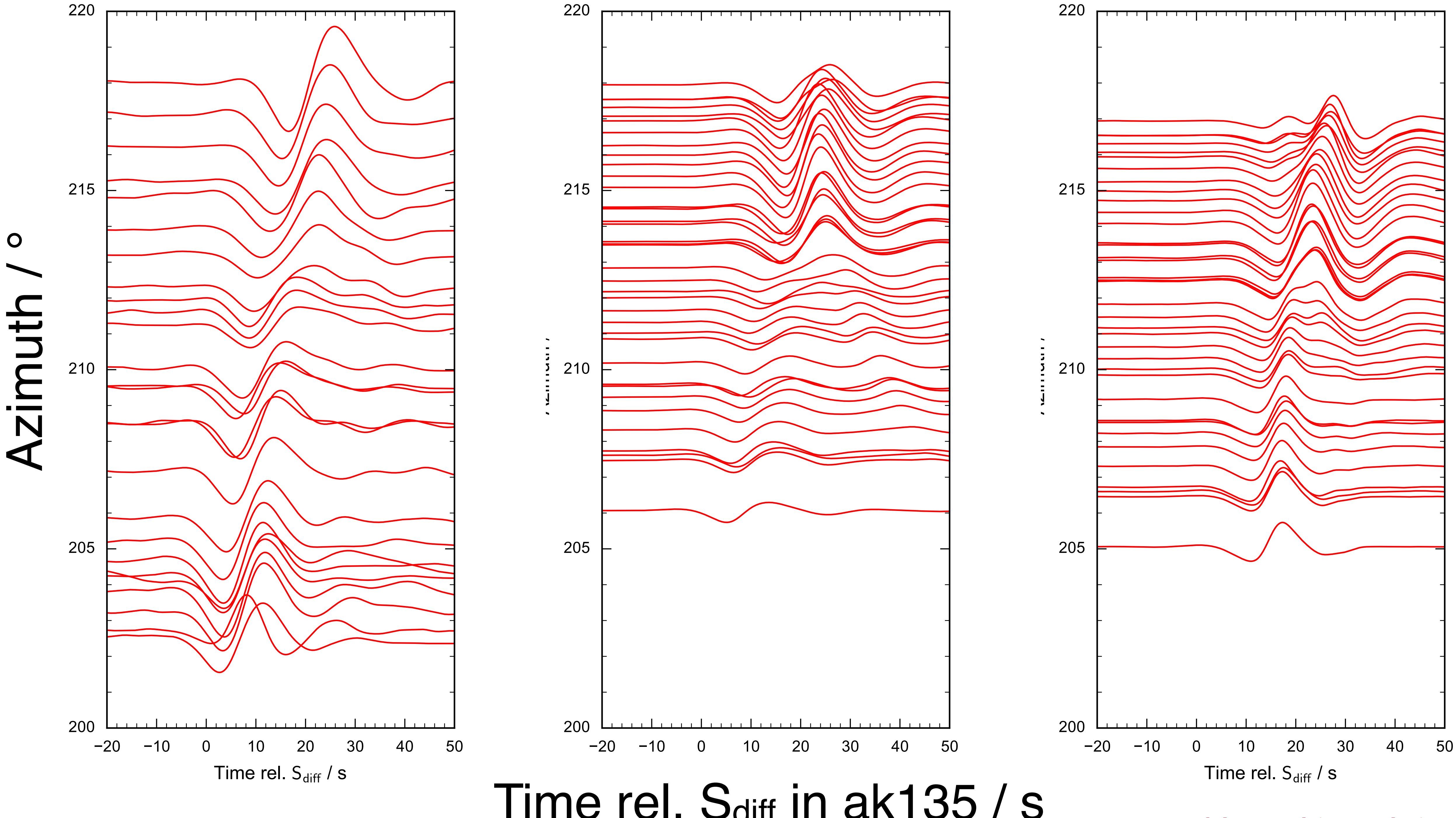
3D effect: seismic simulations



Nowacki et al., in prep.

Synthetics *v.* data





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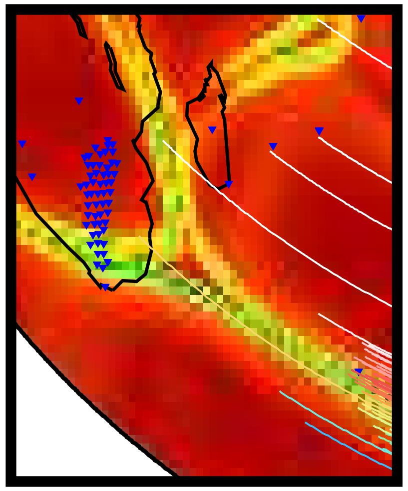
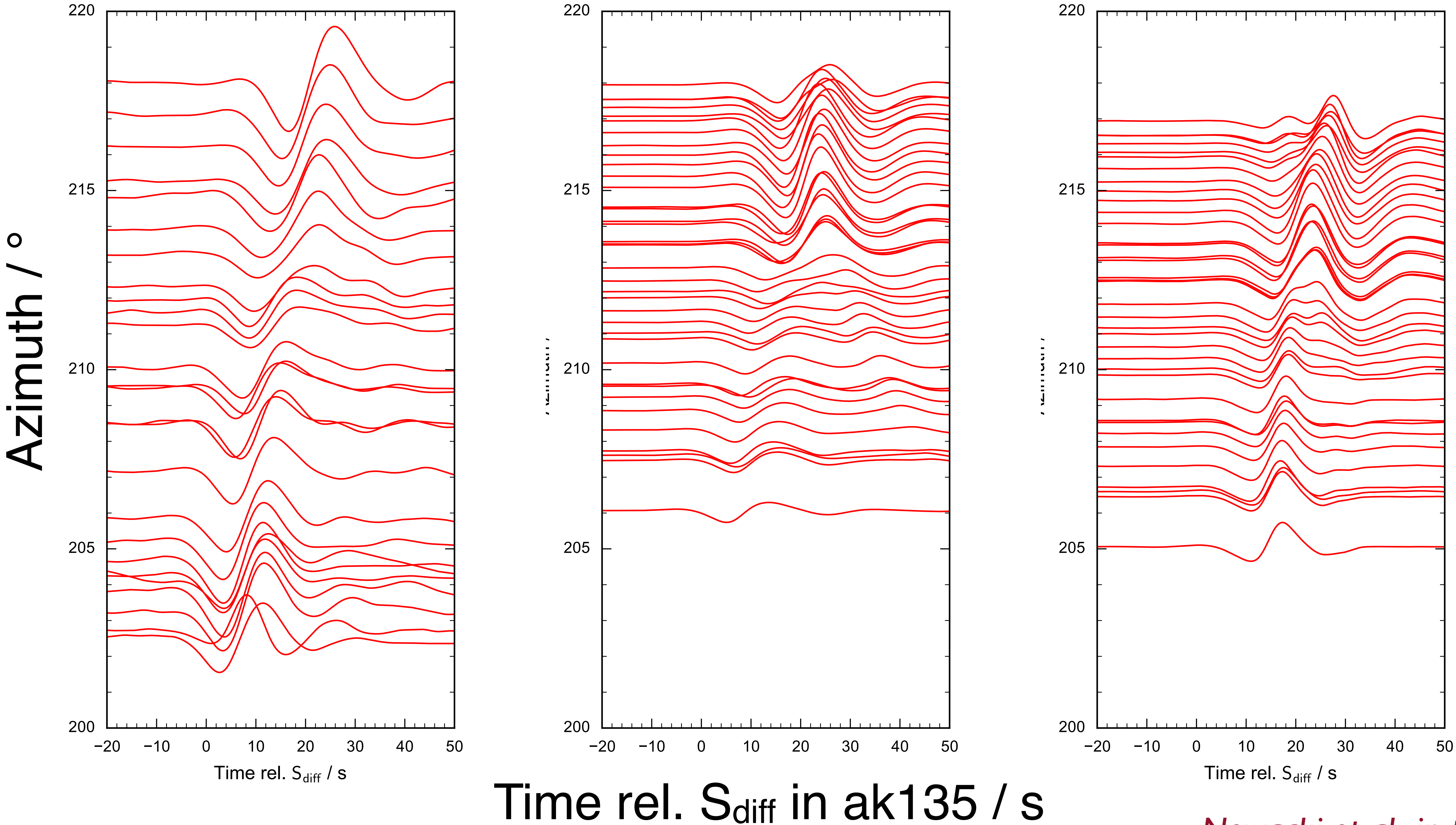


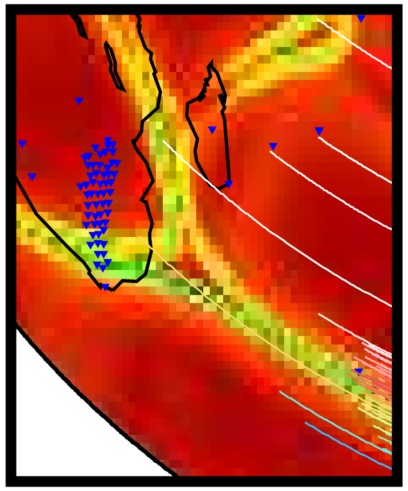
Synthetics v. data

Data

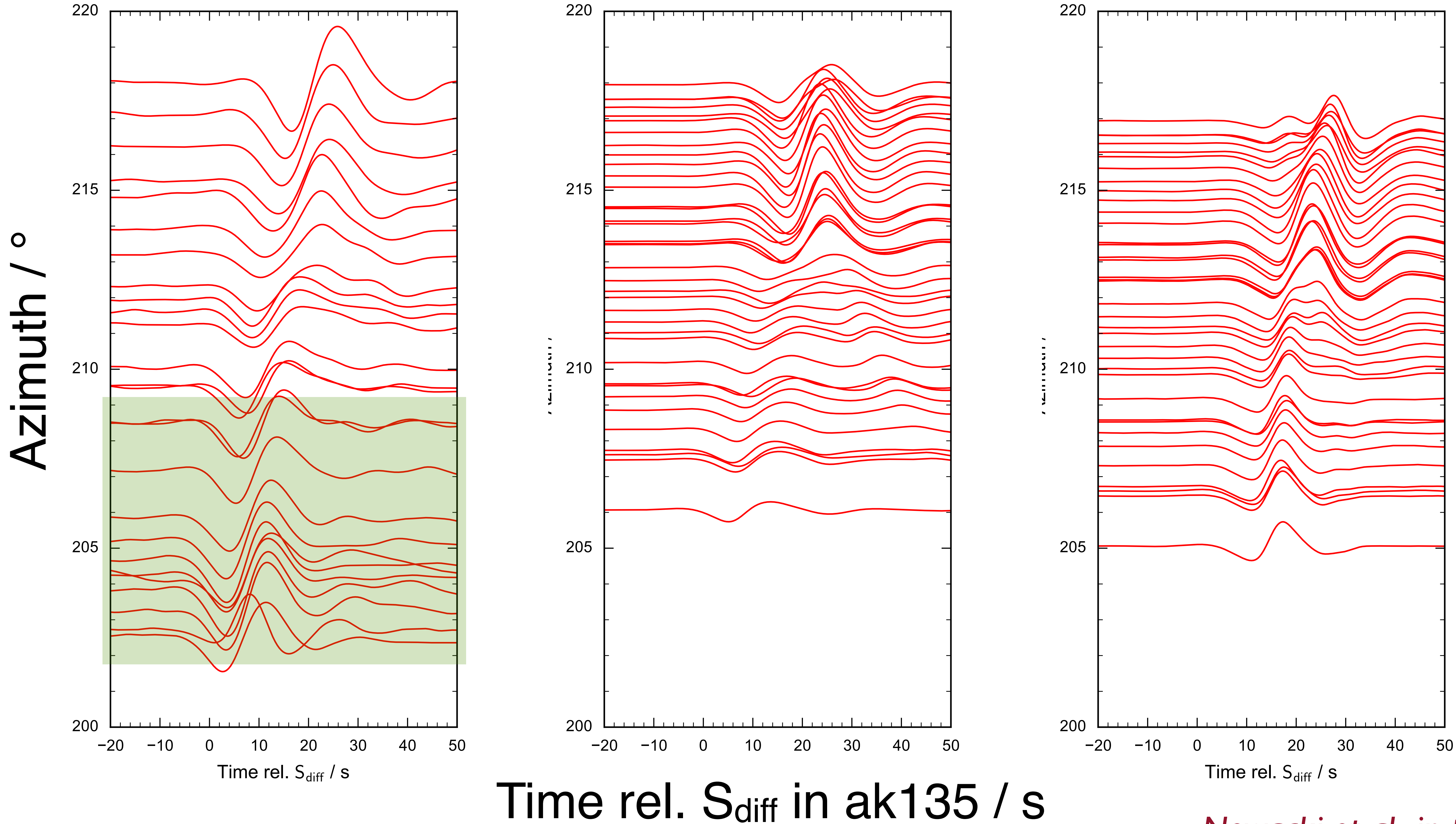


Nowacki et al., in prep.

Synthetics *v.* data

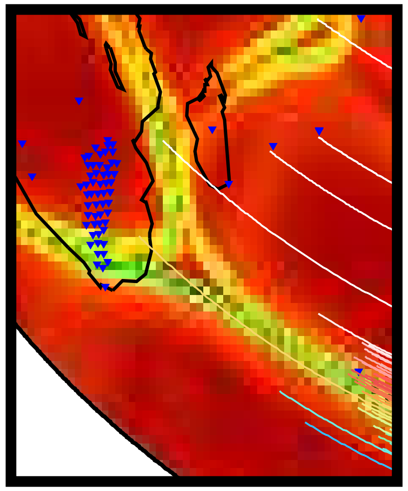


Data

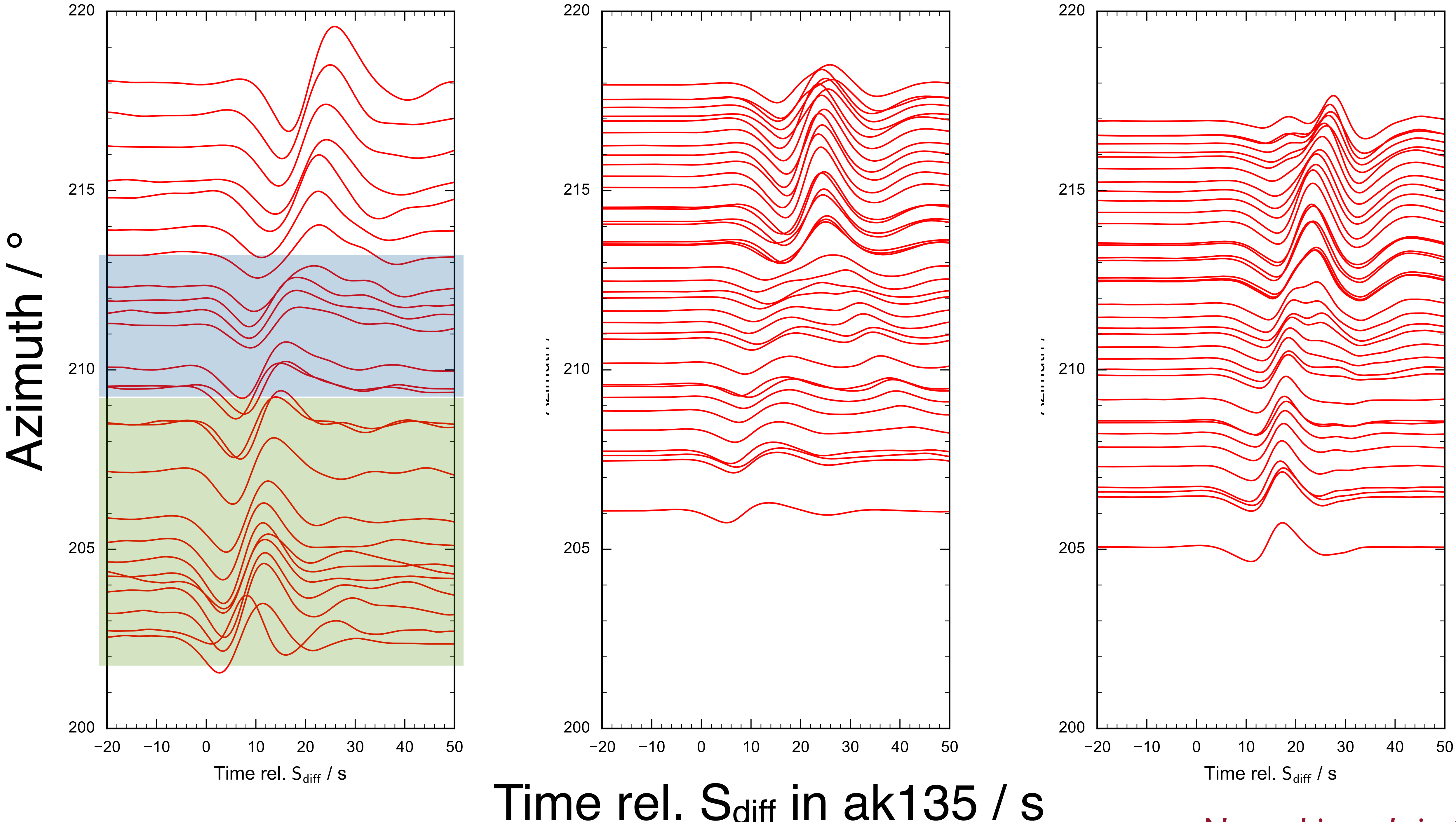


Nowacki et al., in prep.

Synthetics *v.* data

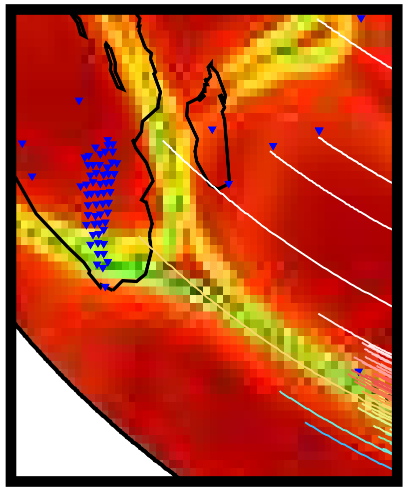


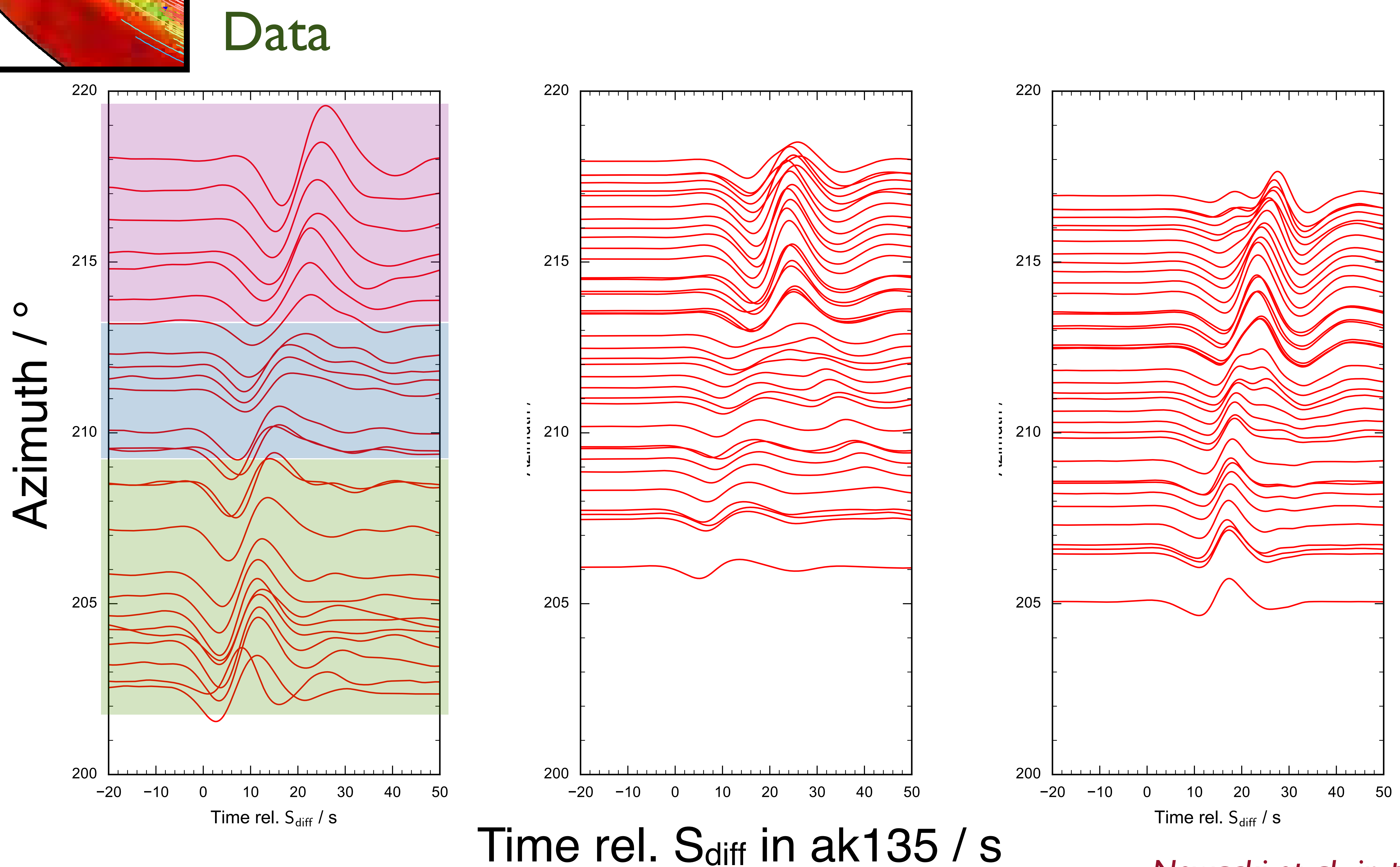
Data



Nowacki et al., in prep.

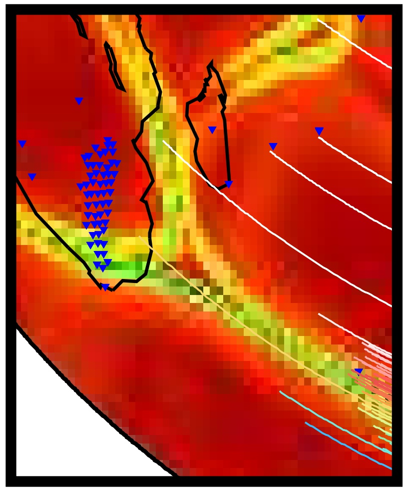
Synthetics v. data



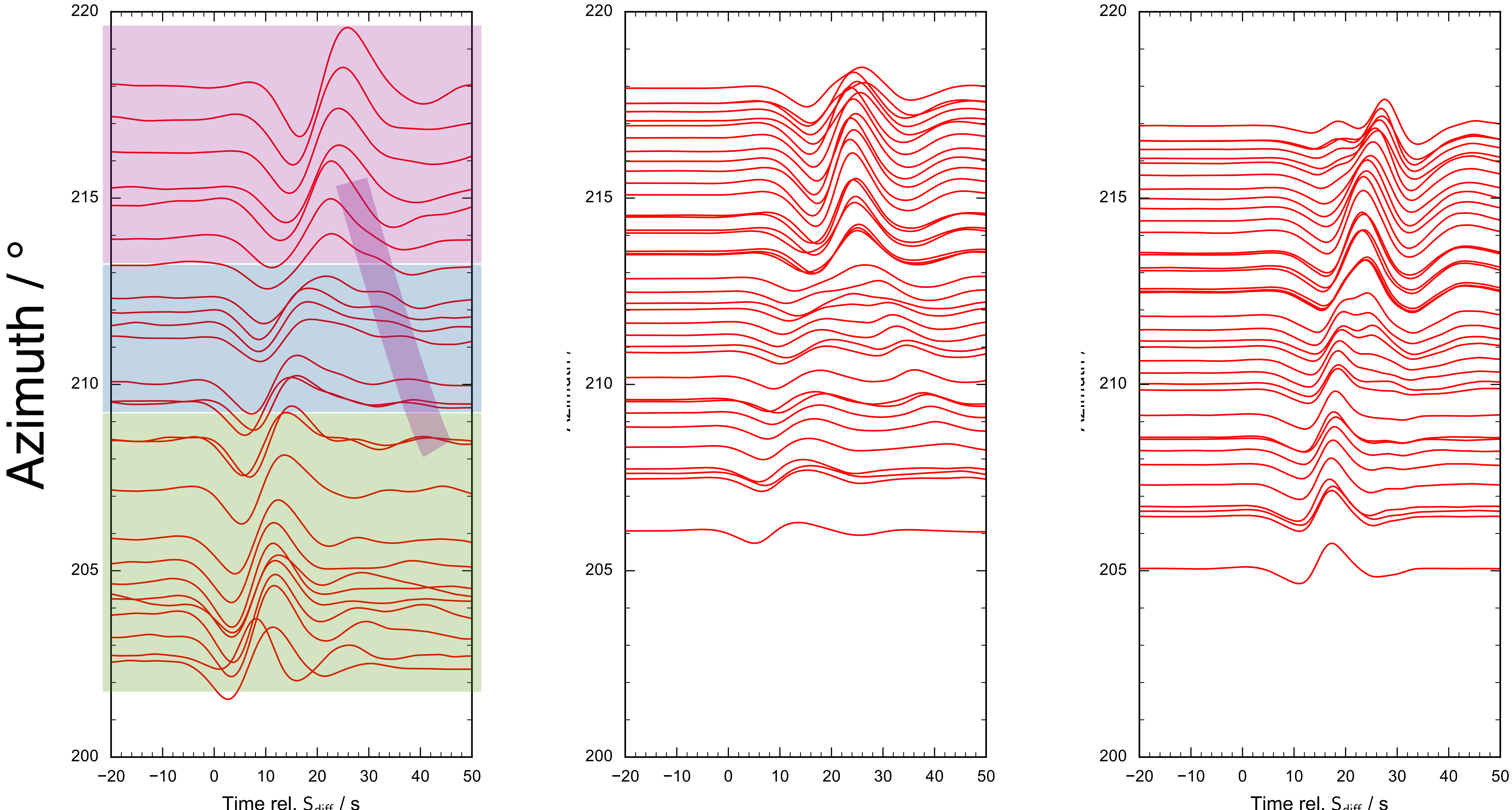


Nowacki et al., in prep.

Synthetics *v.* data

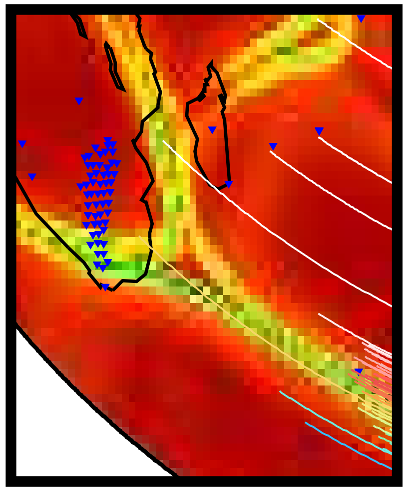


Data



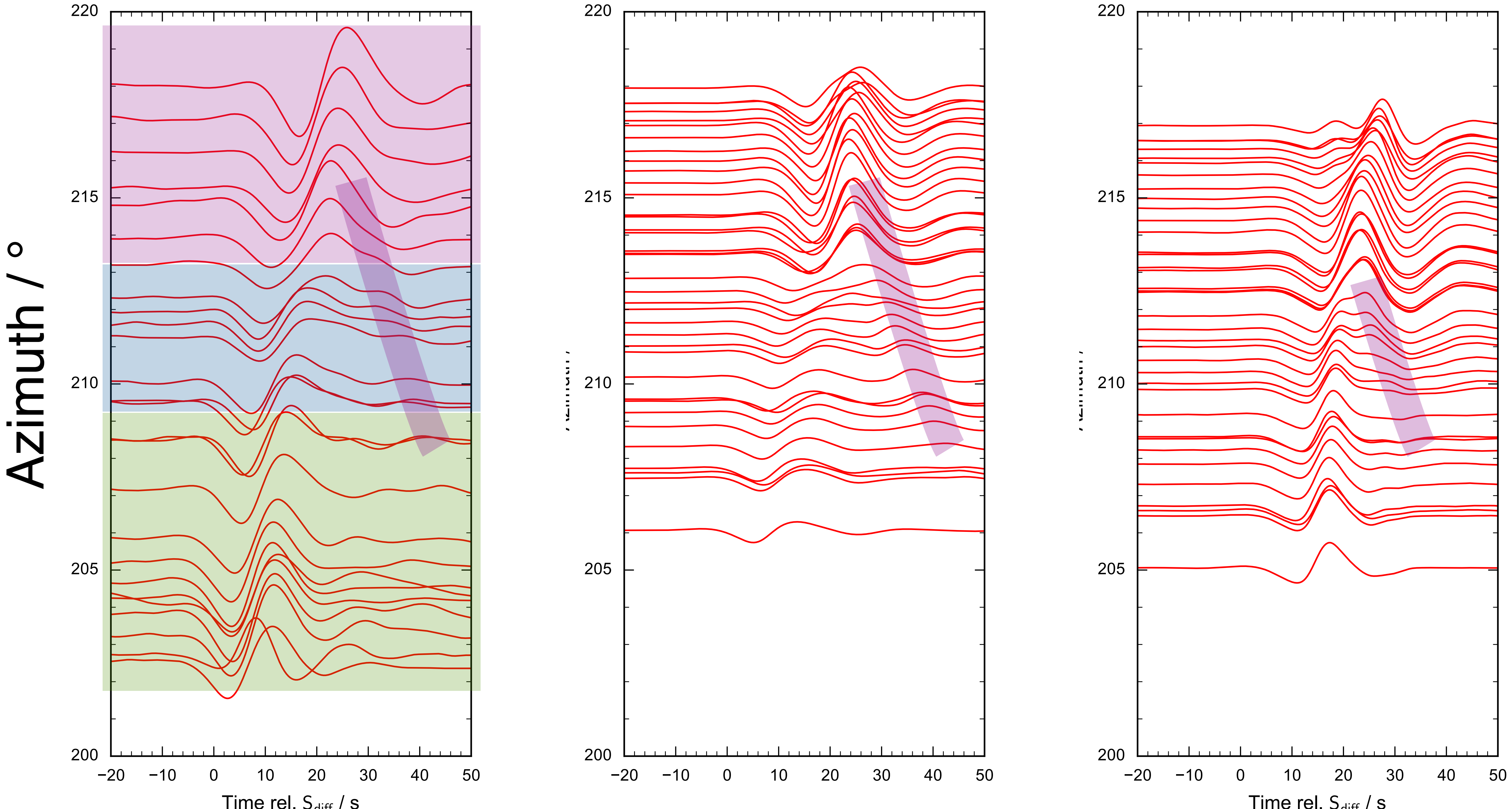
Time rel. S_{diff} in ak135 / s

Nowacki et al., in prep.



Synthetics *v.* data

Data



Time rel. S_{diff} in ak135 / s

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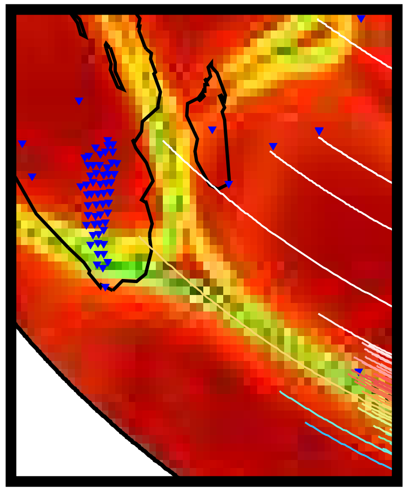
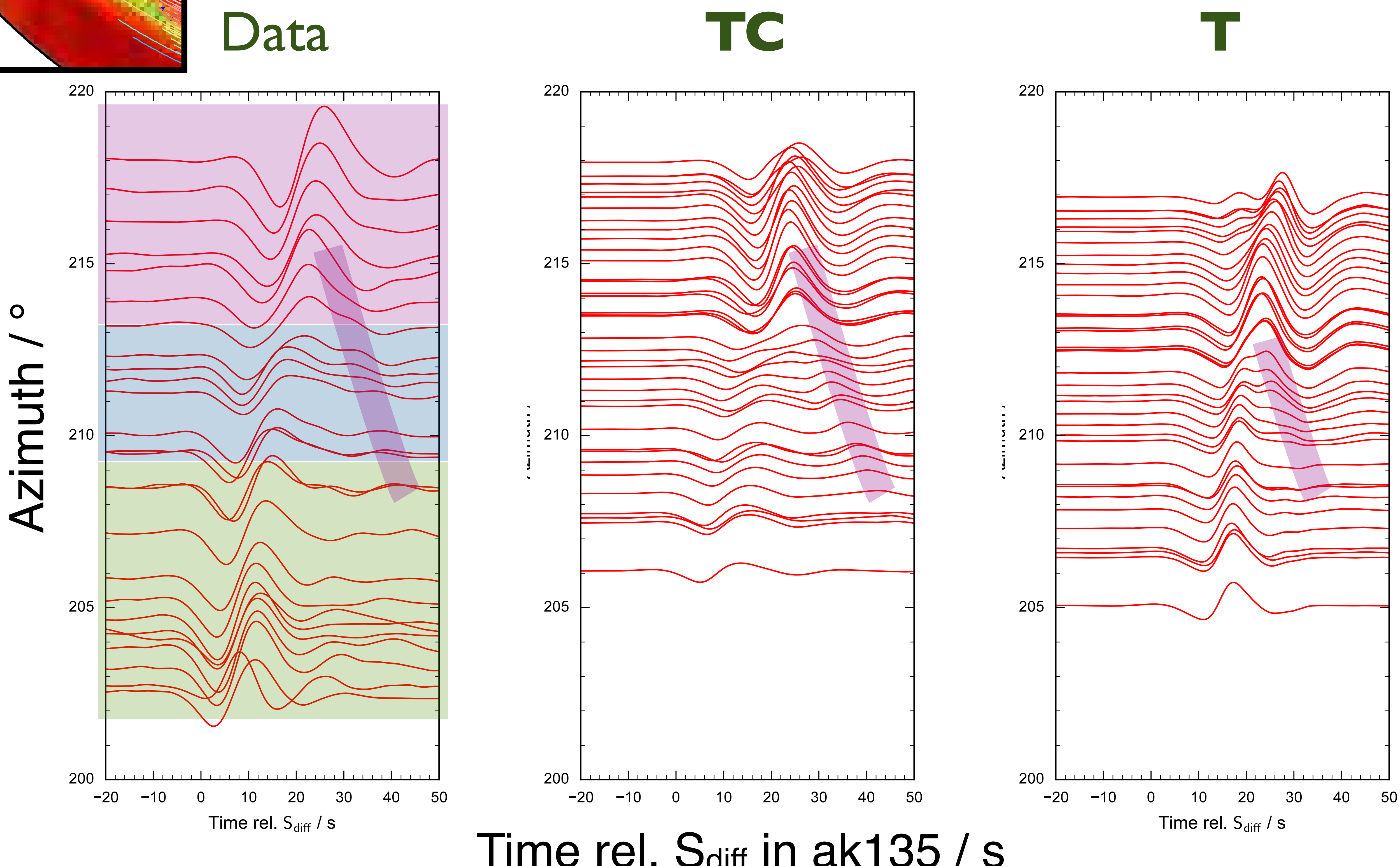
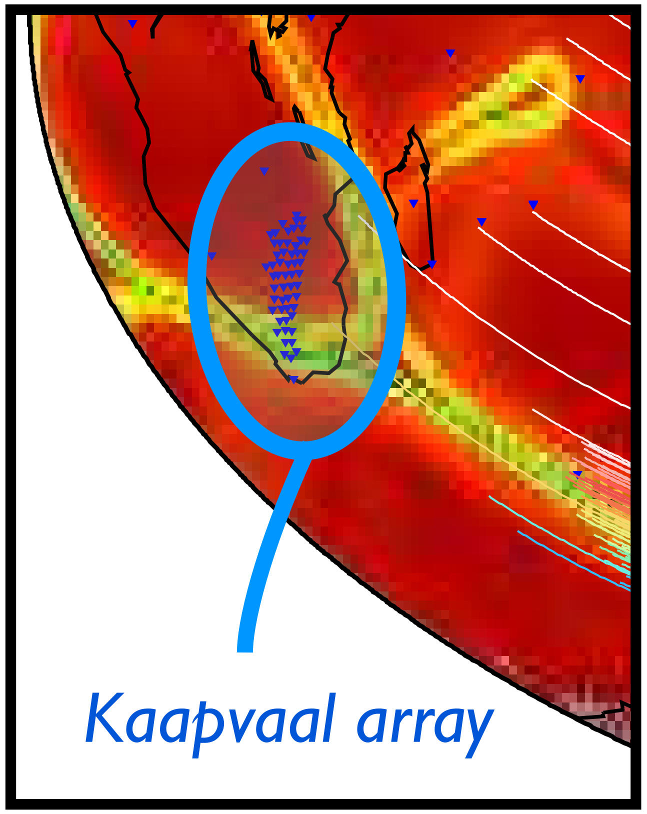
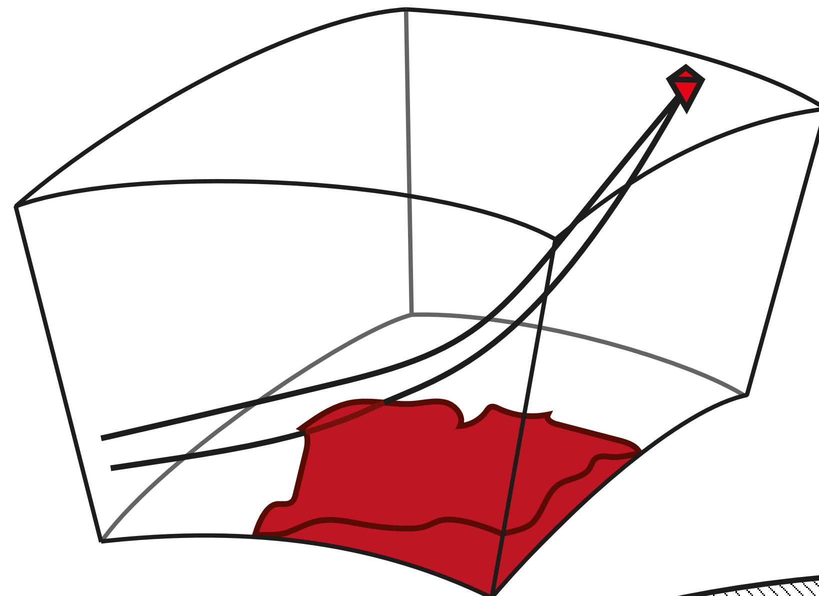


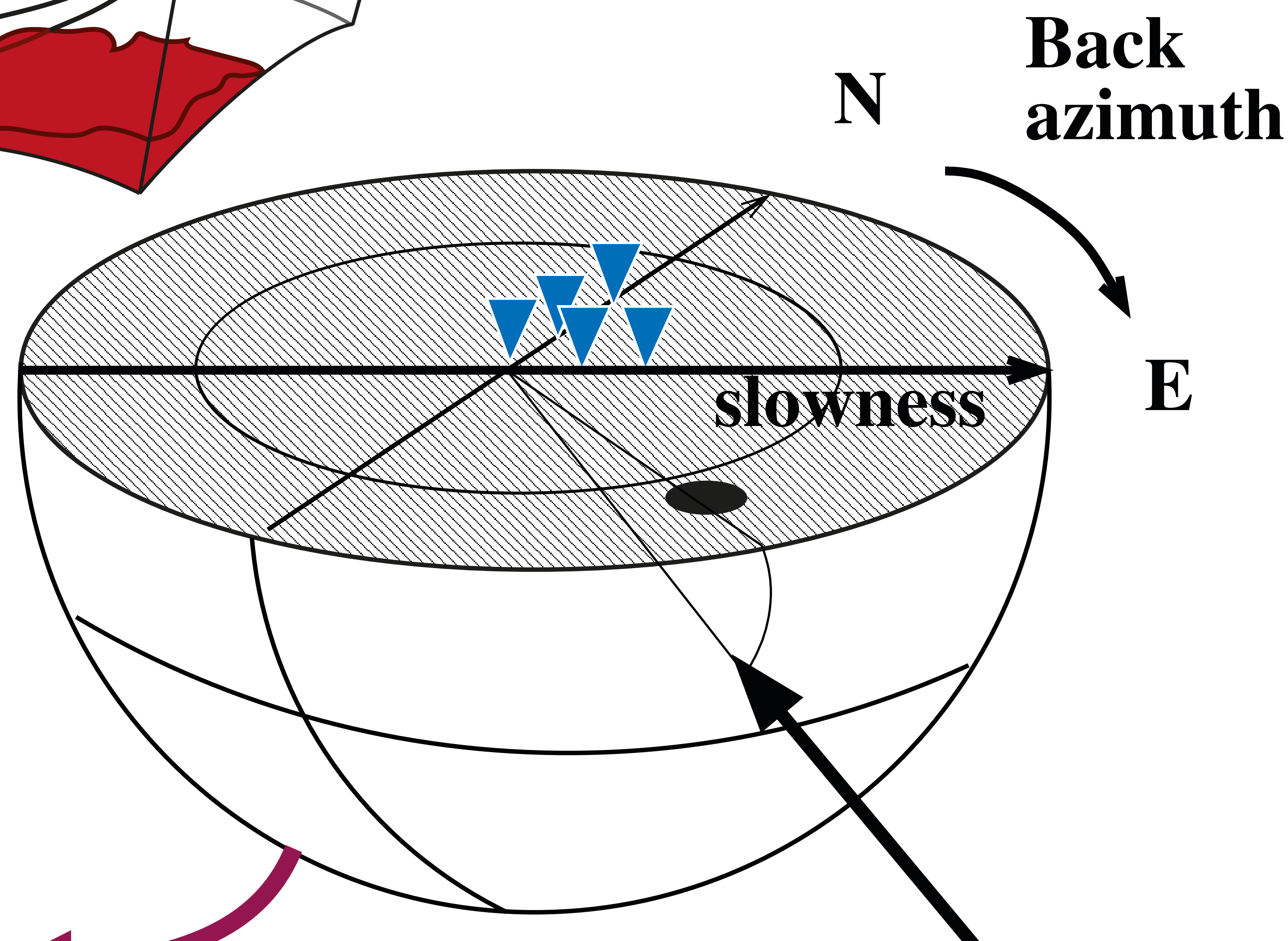


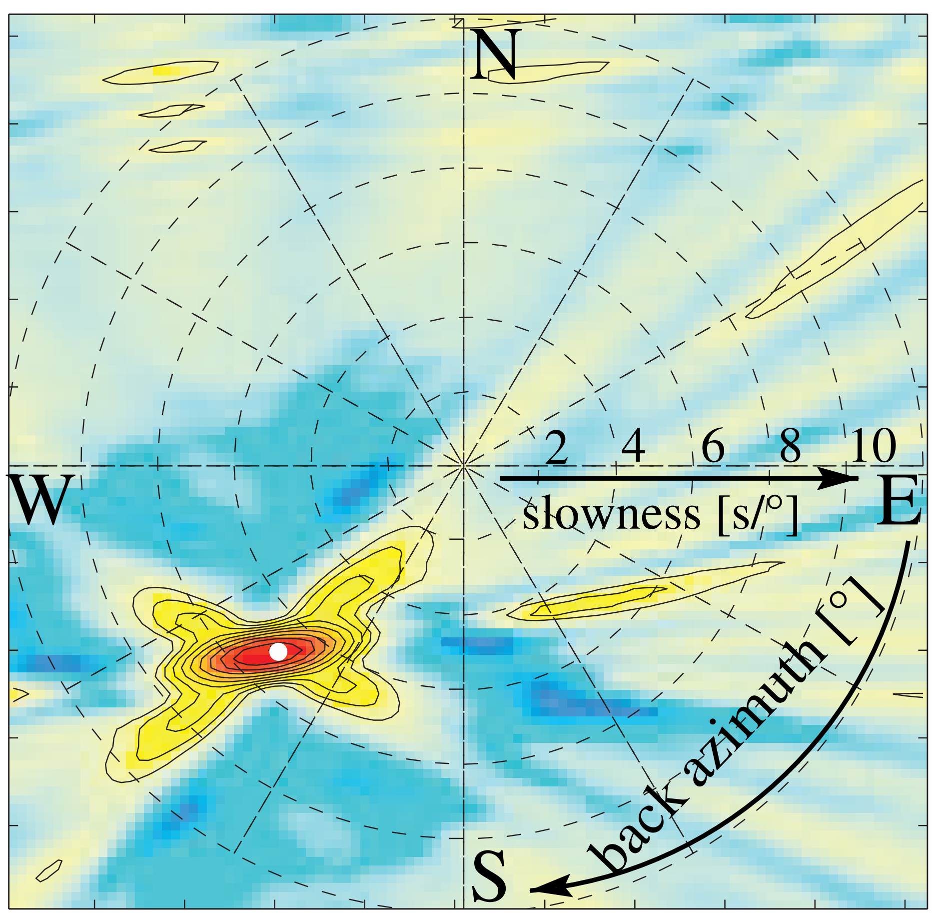
Nowacki et al., in prep.

Frequency-wavenumber (*fk*) analysis



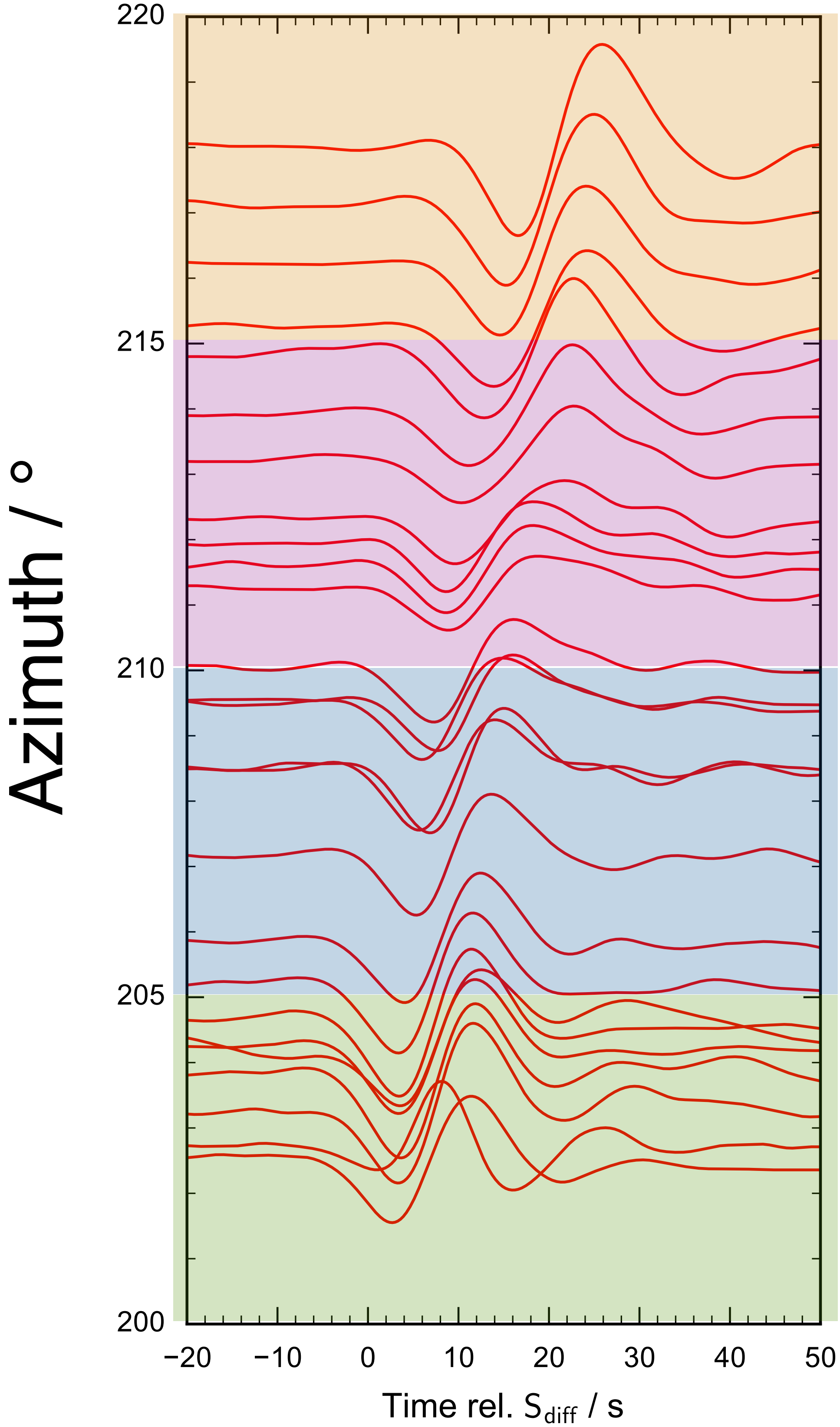




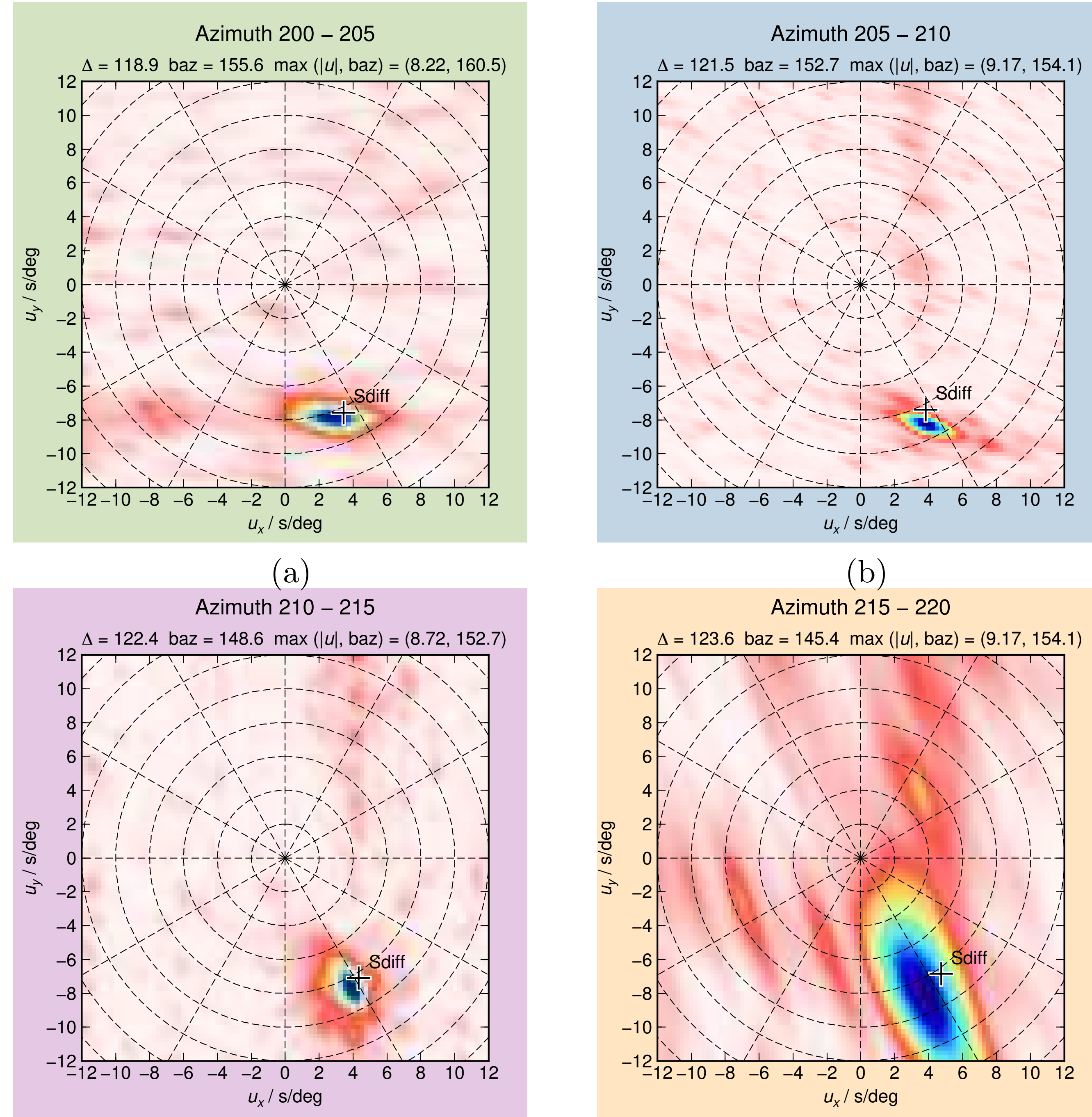


Rost & Thomas, Rev Geophys, 2002

fk analysis: multipathing



Sdiff, unfiltered, 3rd-order phaseweighted

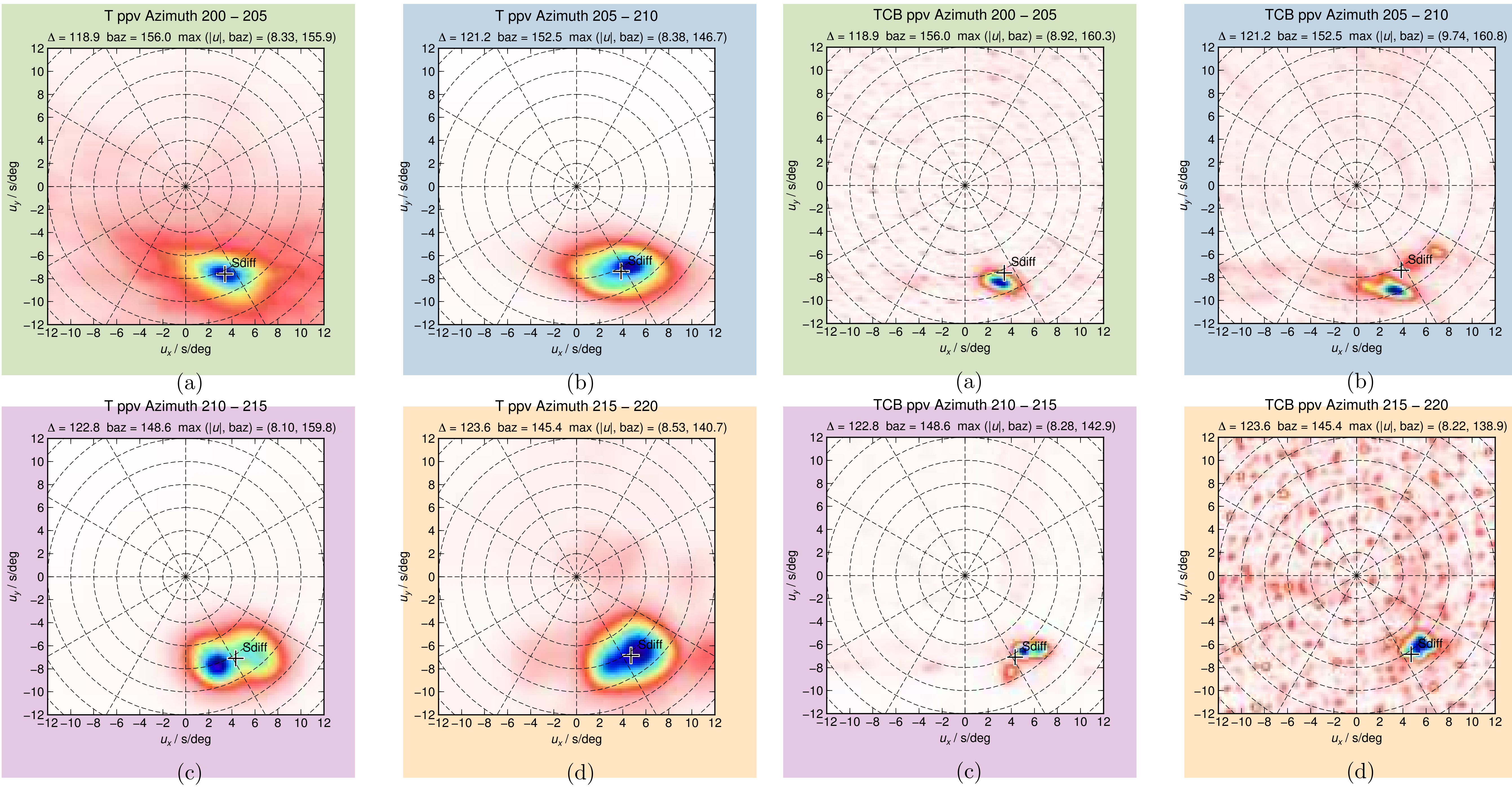


Data

fk analysis: multipathing

100-15 s

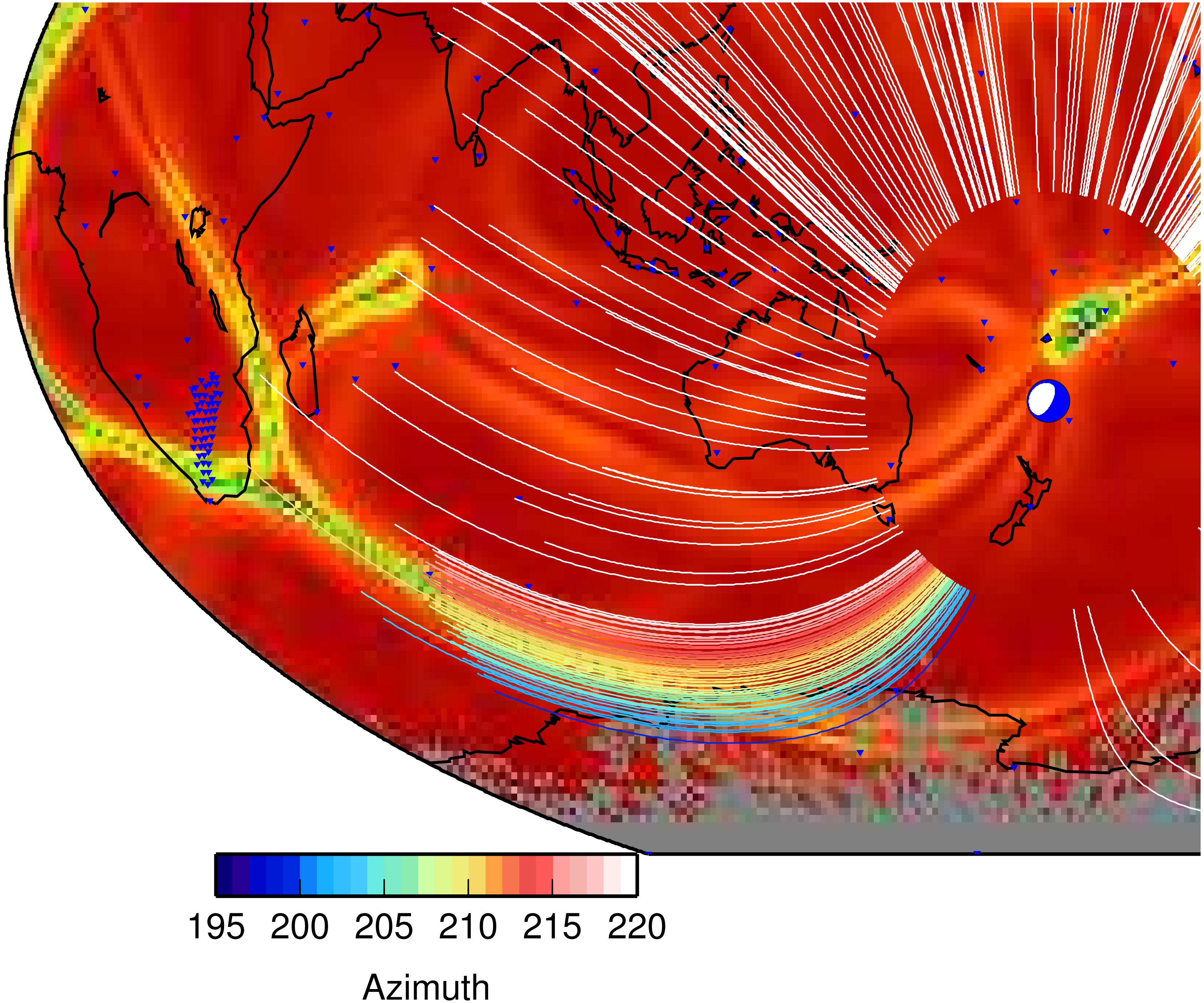
100-5 s



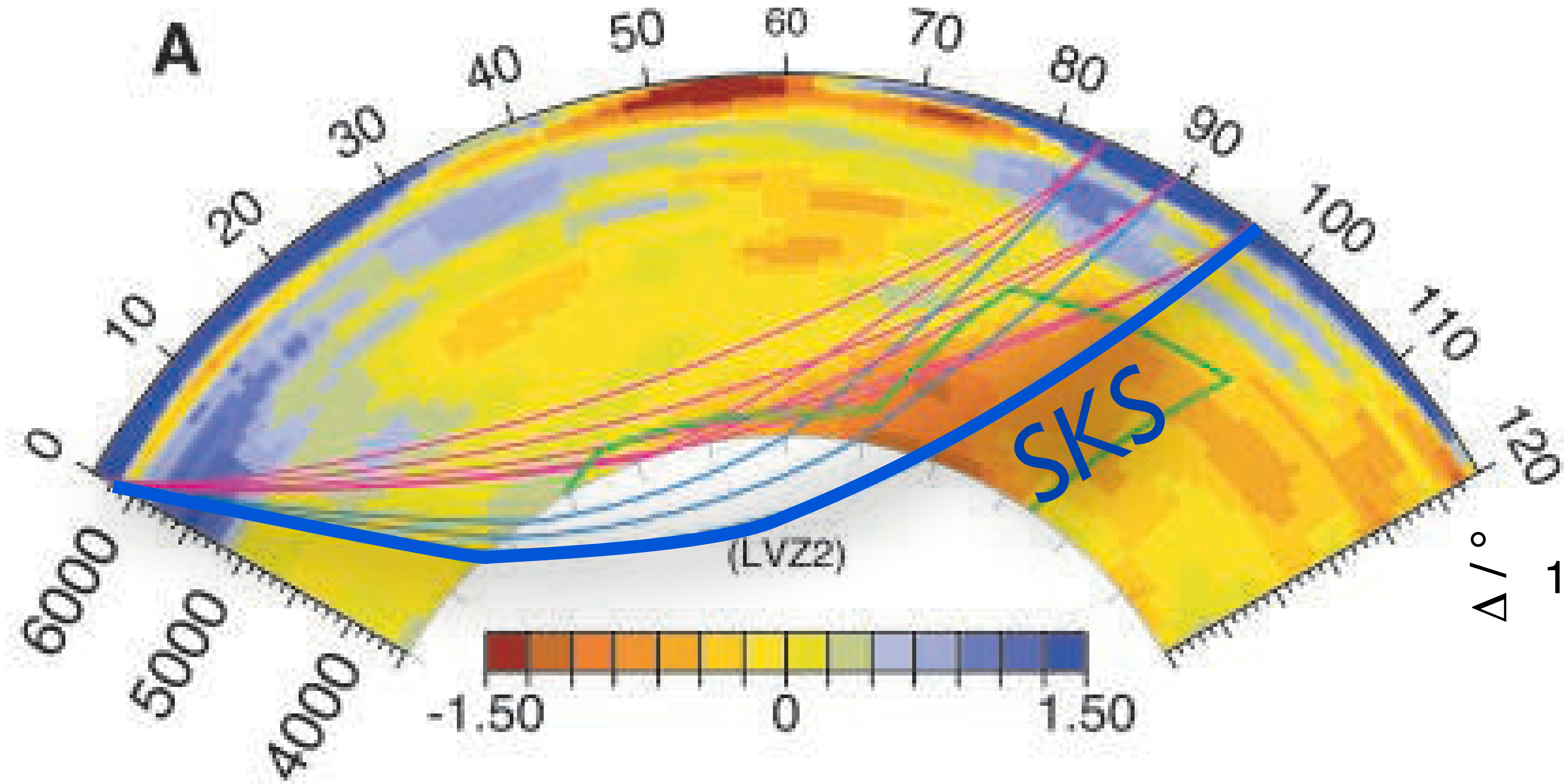
T

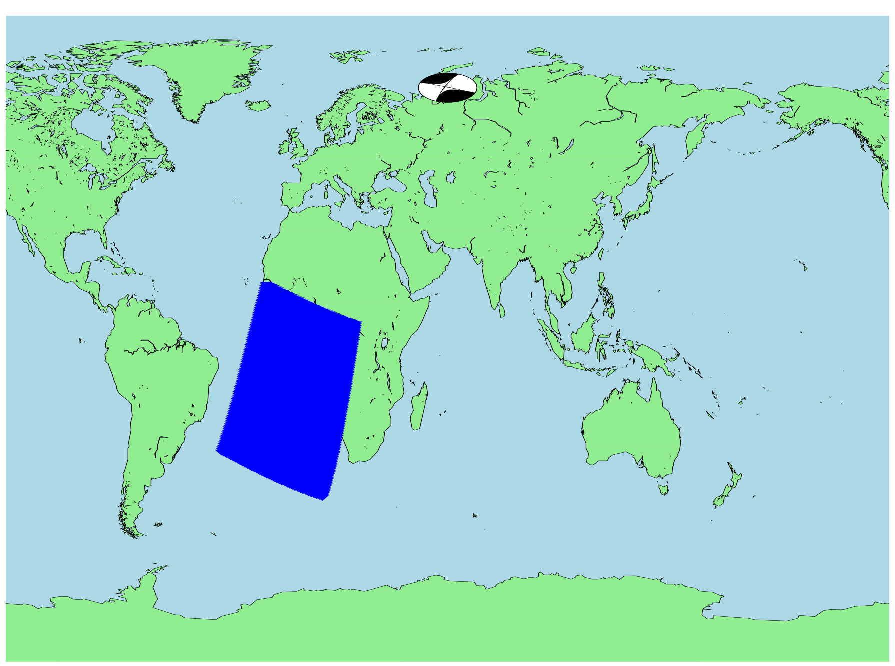
TC

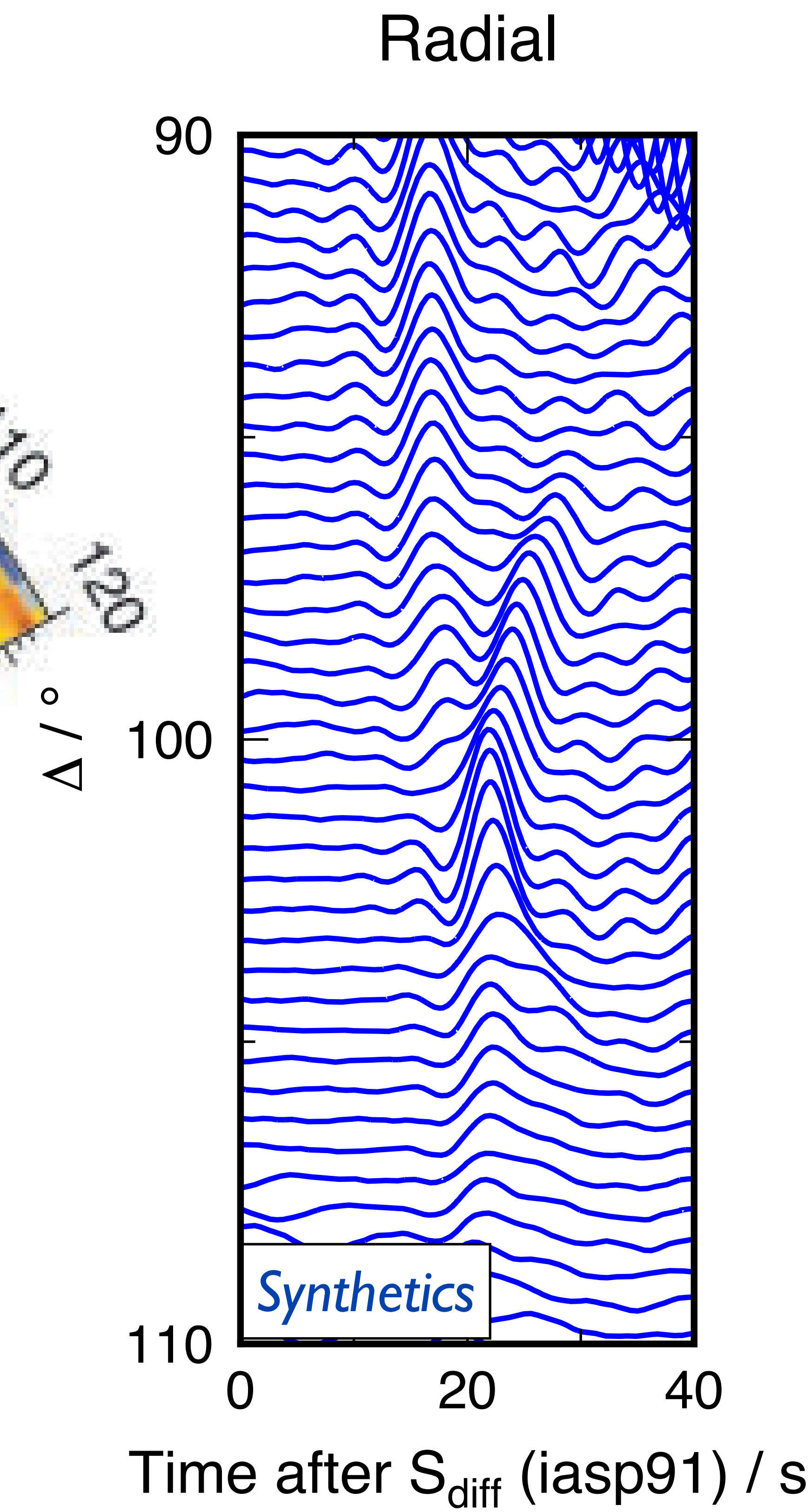
Multipathing in S_{diff}



‘Mapping’ with SKS



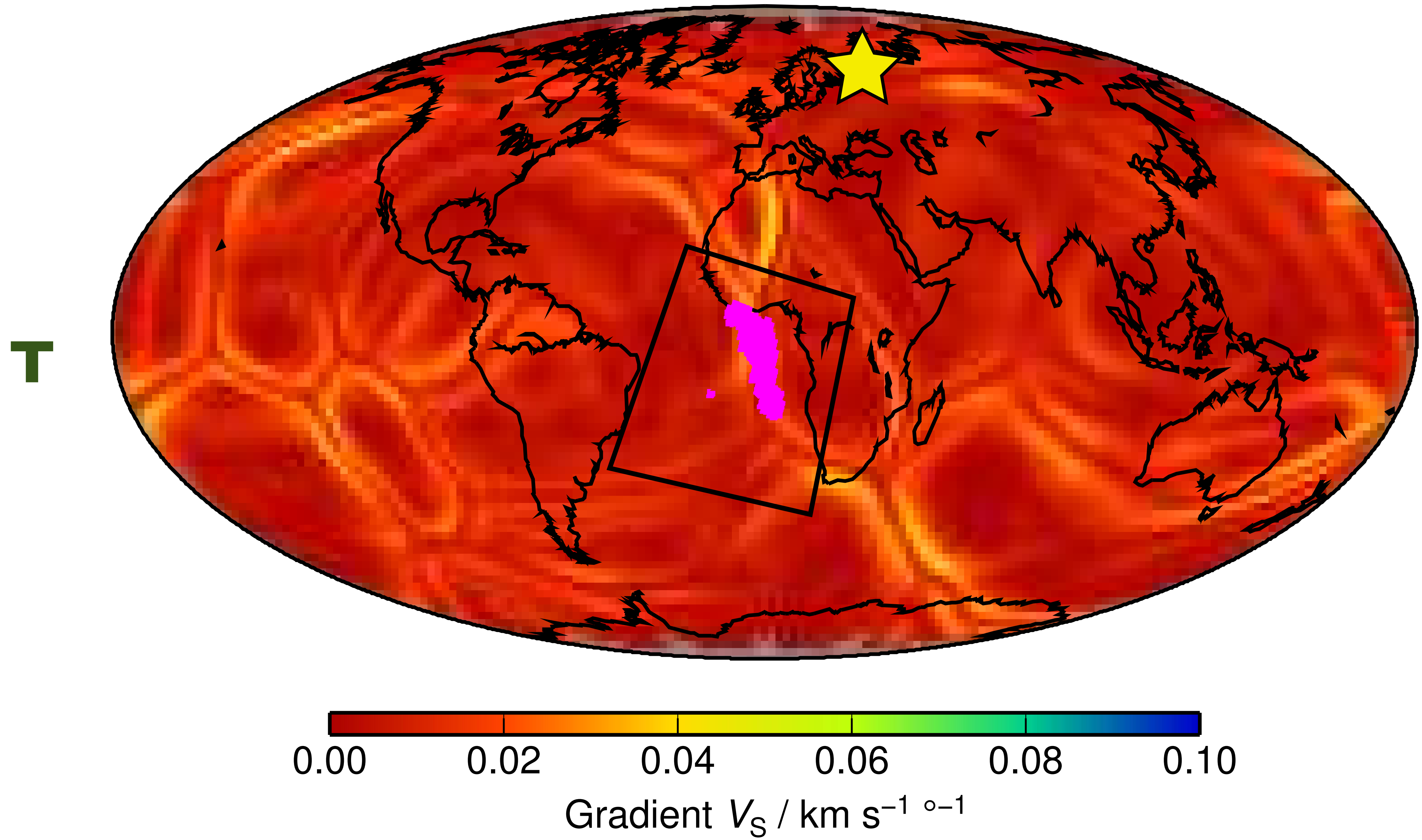




Ni et al., Science, 2002

‘Mapping’ with SKS

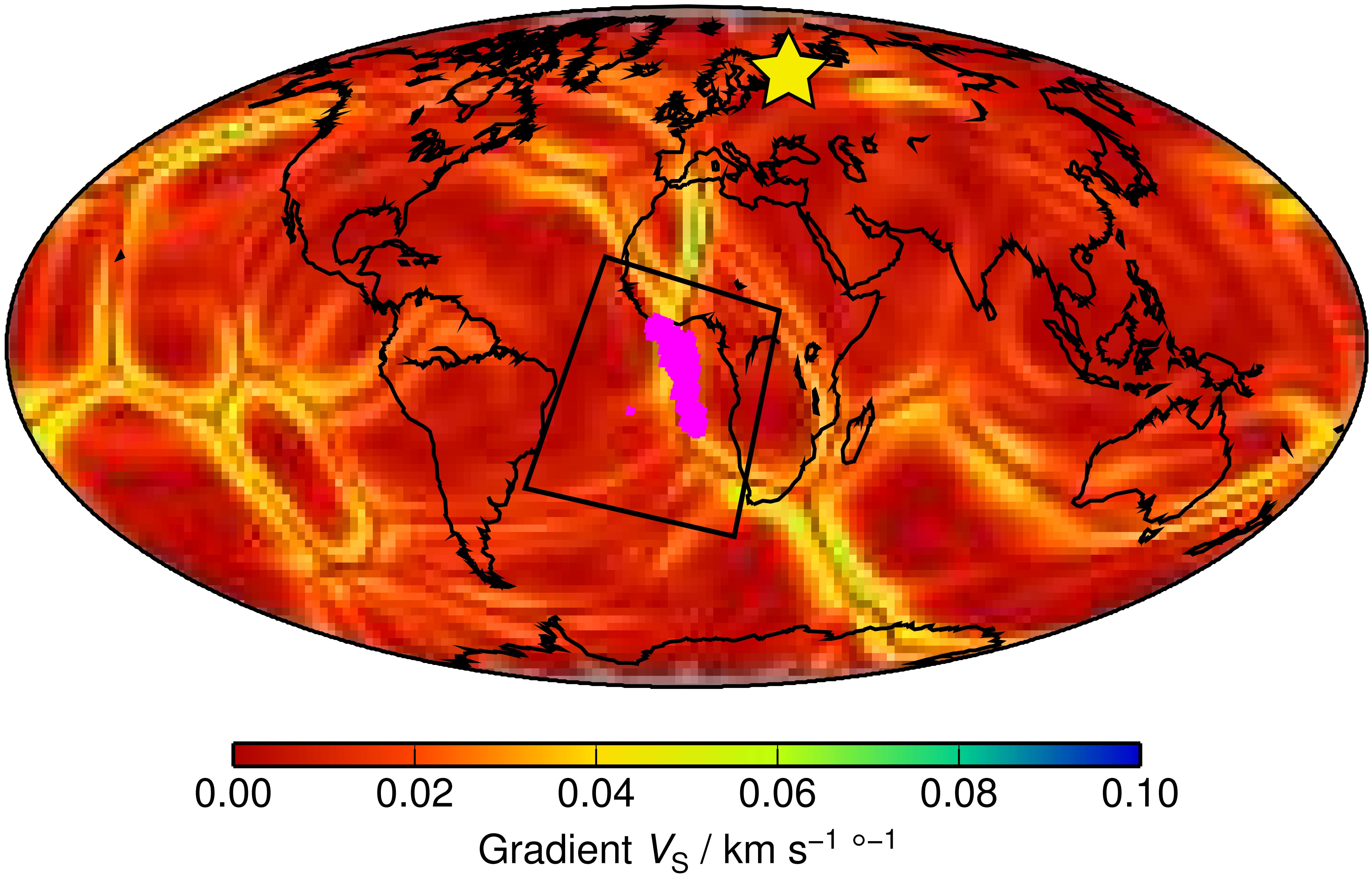
T no ppv, paths to 3680 km radius, $|\nabla V_S|$ 50 km above CMB



‘Mapping’ with SKS

T no ppv, paths to 3680 km radius, $|\nabla V_S|$ 100 km above CMB

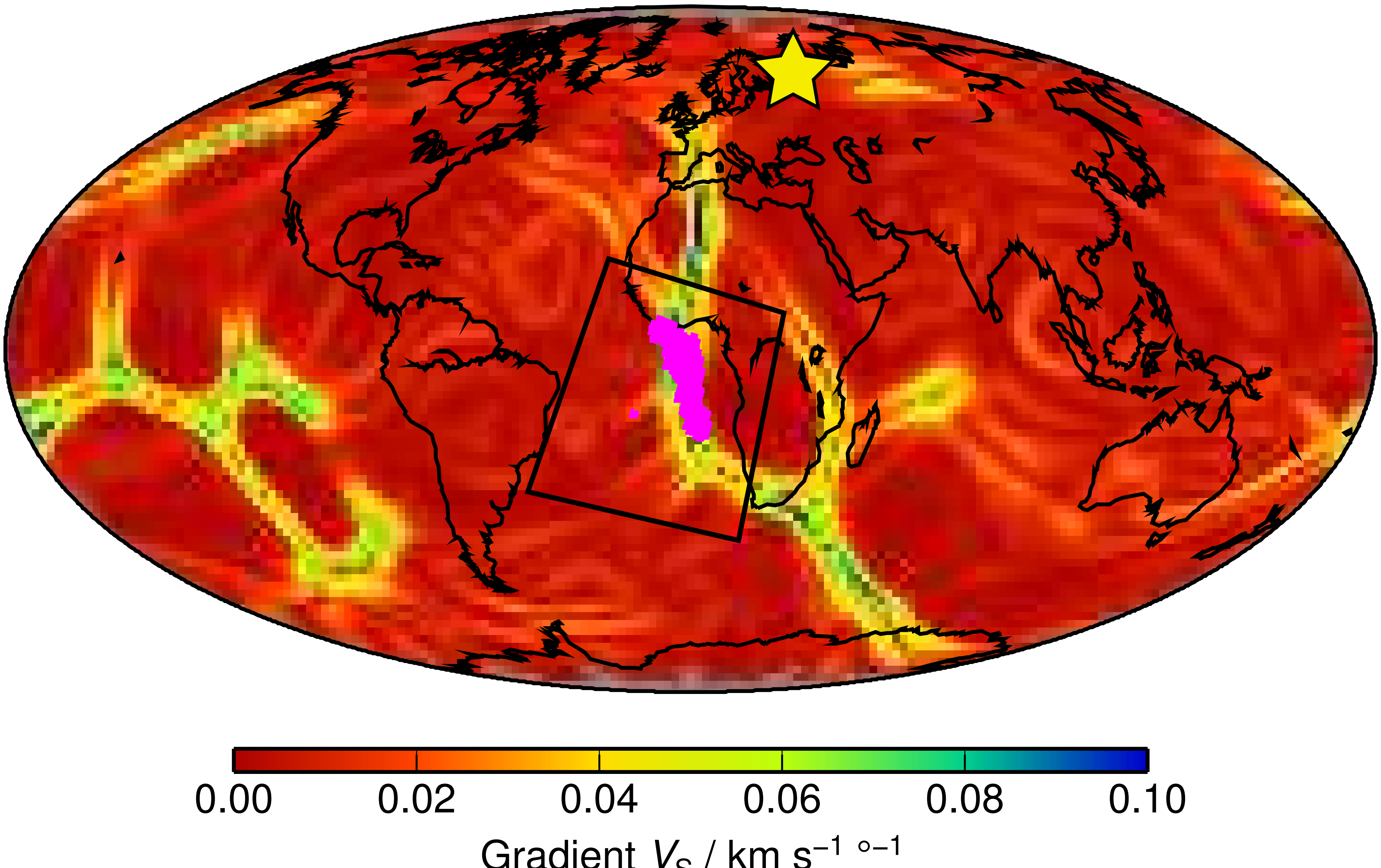
T



‘Mapping’ with SKS

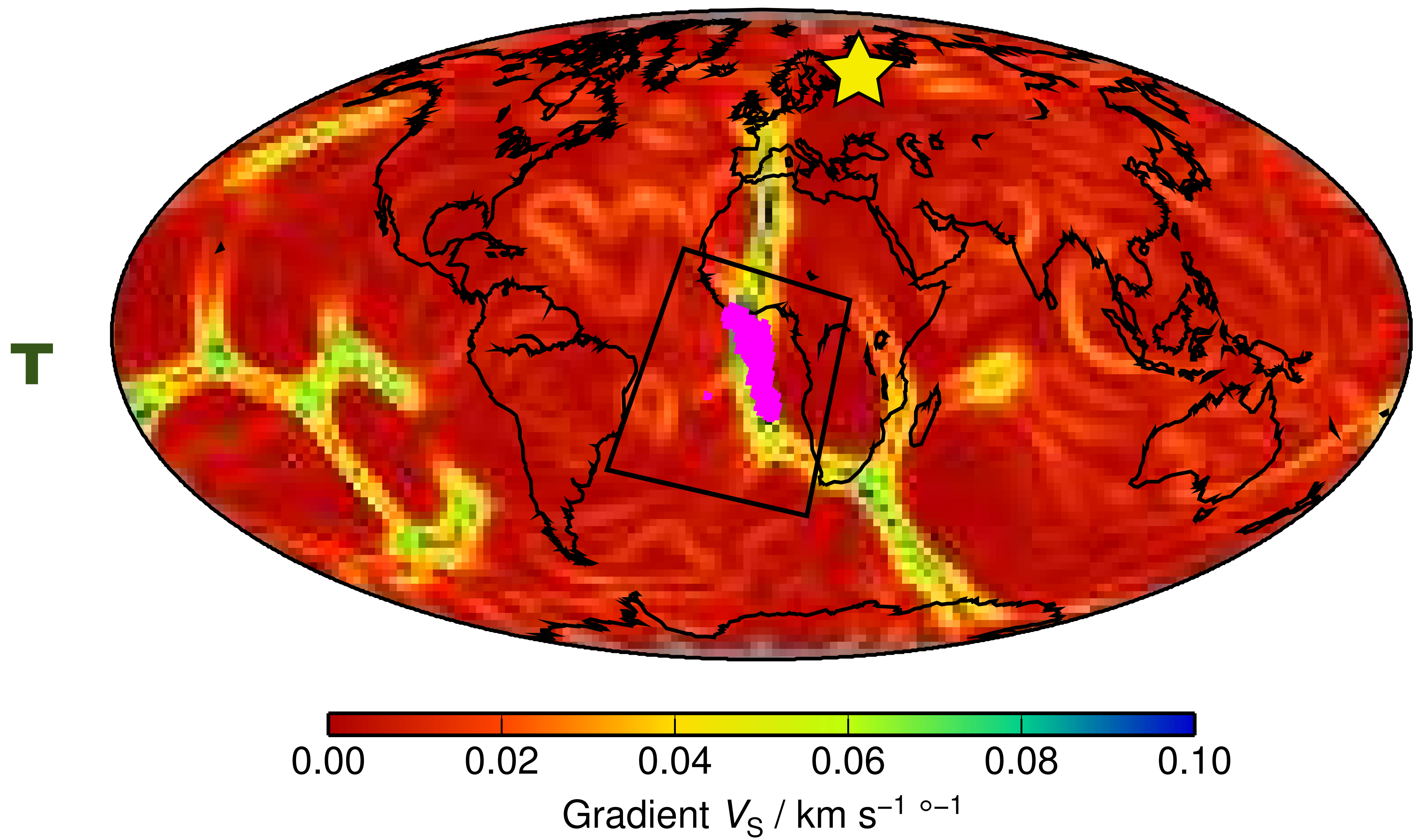
T no ppv, paths to 3680 km radius, $|\nabla V_S|$ 300 km above CMB

T



‘Mapping’ with SKS

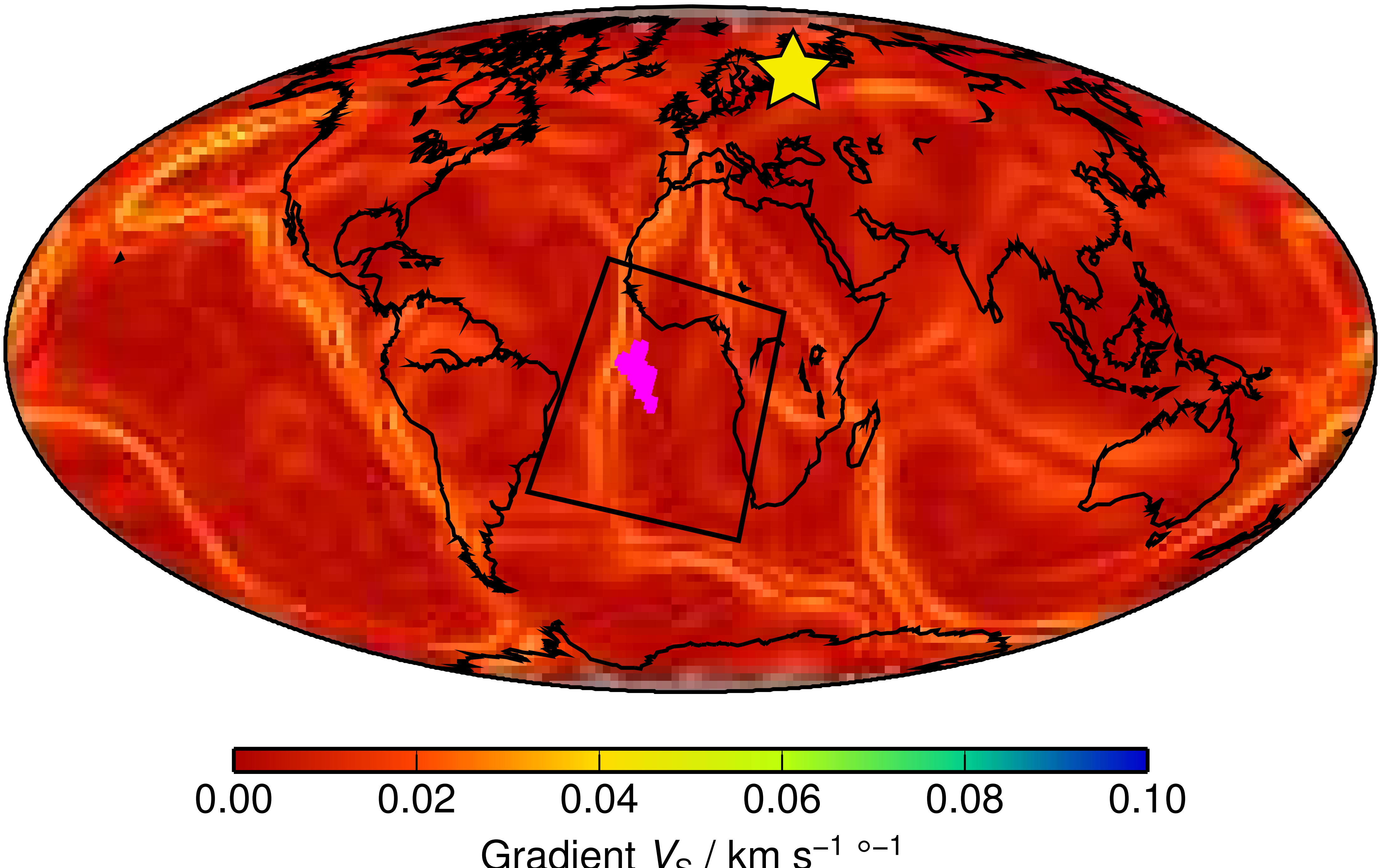
T no ppv, paths to 3680 km radius, $|\nabla V_S|$ 400 km above CMB



‘Mapping’ with SKS

TCB no ppv, paths to 3680 km radius, $|\nabla V_S|$ 50 km above CMB

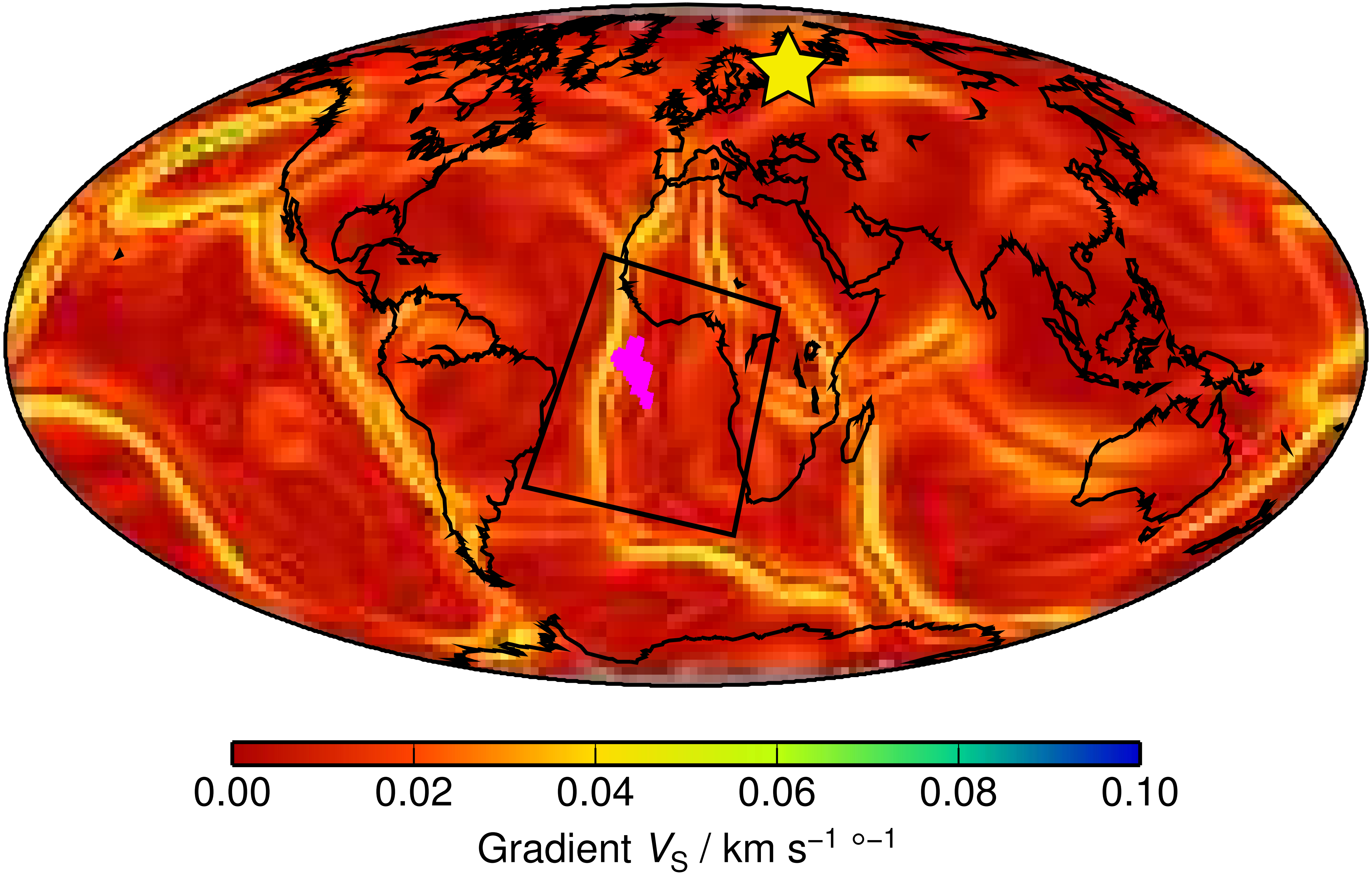
TC



‘Mapping’ with SKS

TCB no ppv, paths to 3680 km radius, $|\nabla V_S|$ 100 km above CMB

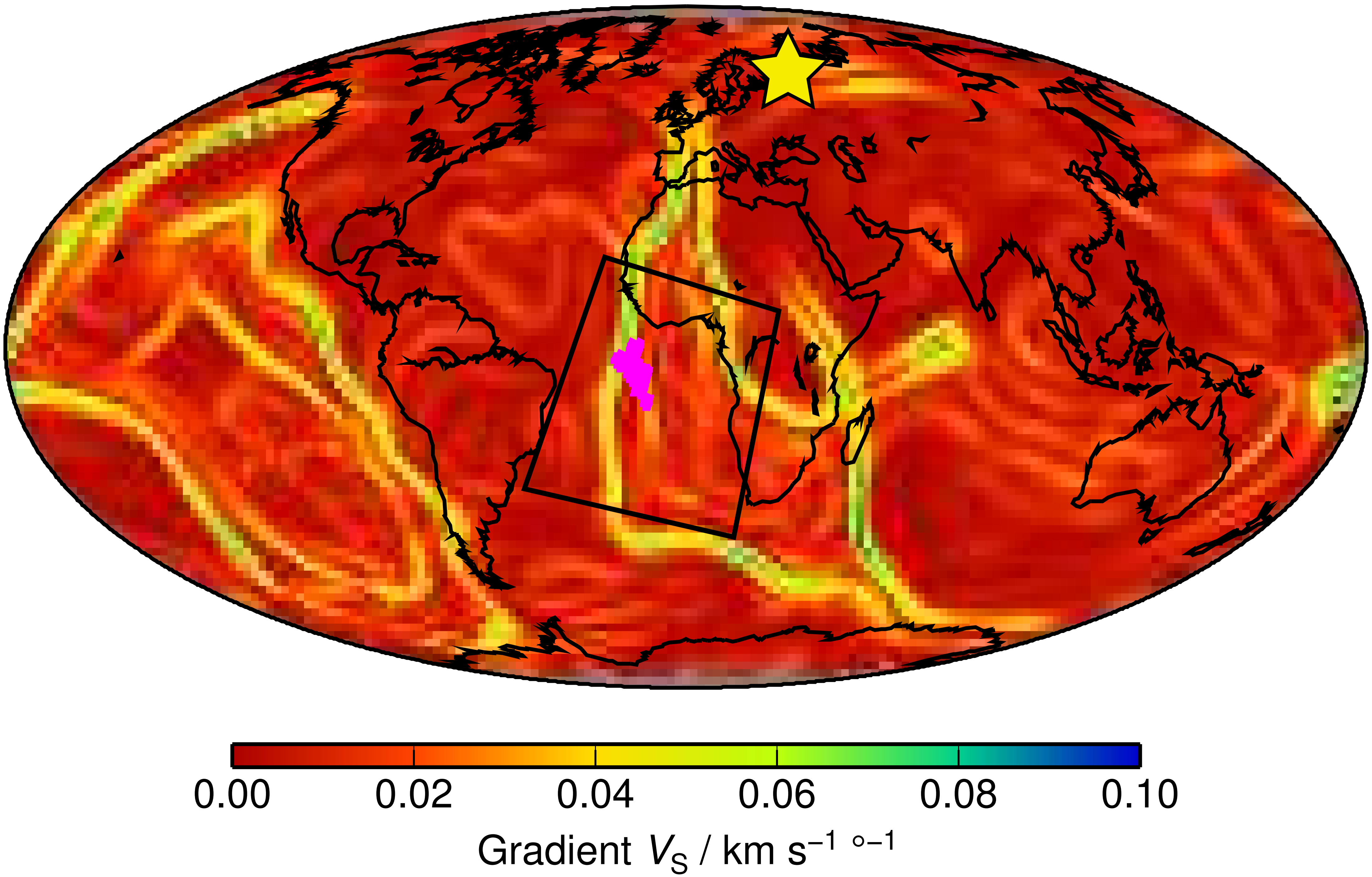
TC



‘Mapping’ with SKS

TCB no ppv, paths to 3680 km radius, $|\nabla V_S|$ 300 km above CMB

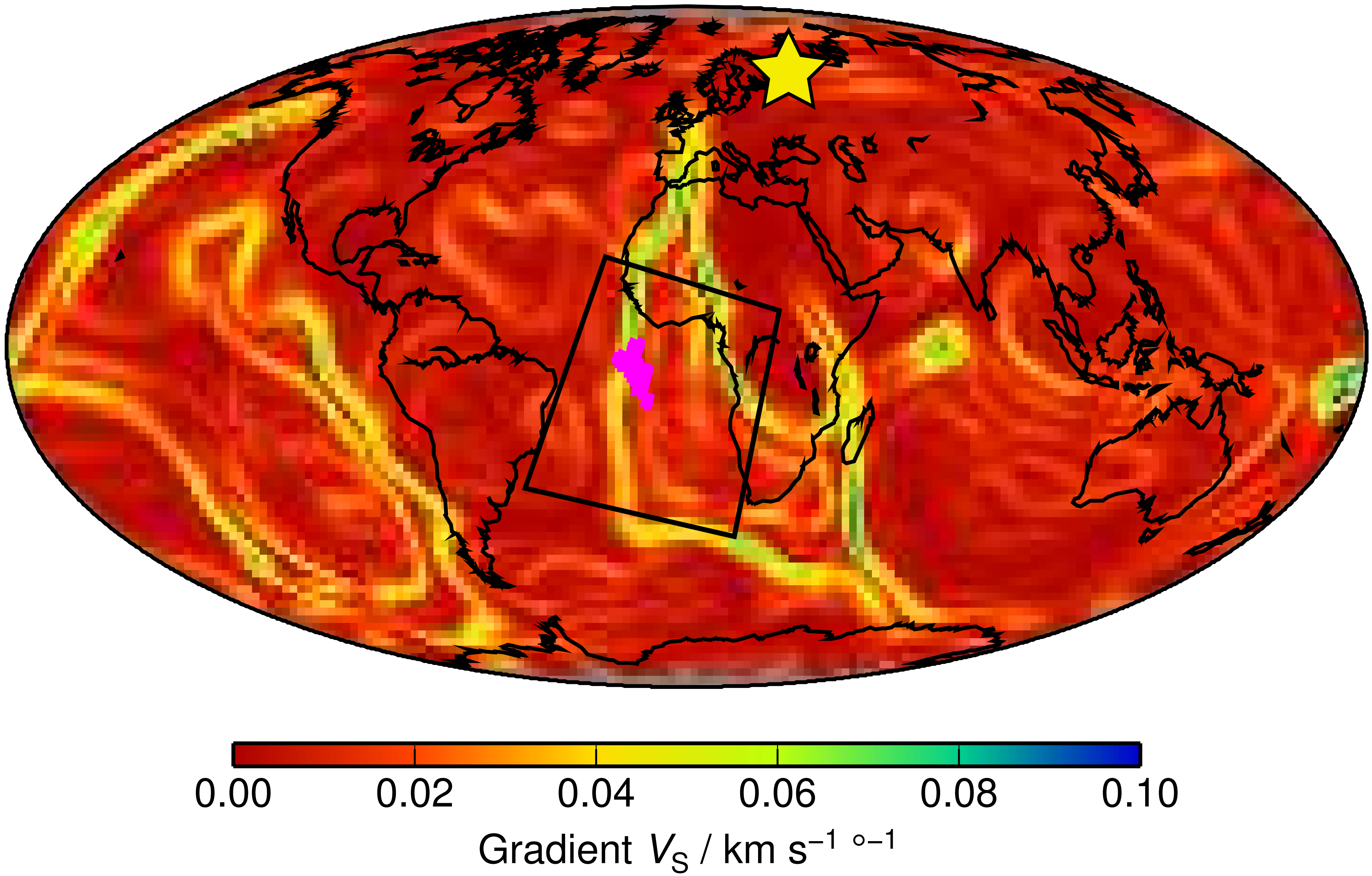
TC



‘Mapping’ with SKS

TCB no ppv, paths to 3680 km radius, $|\nabla V_S|$ 400 km above CMB

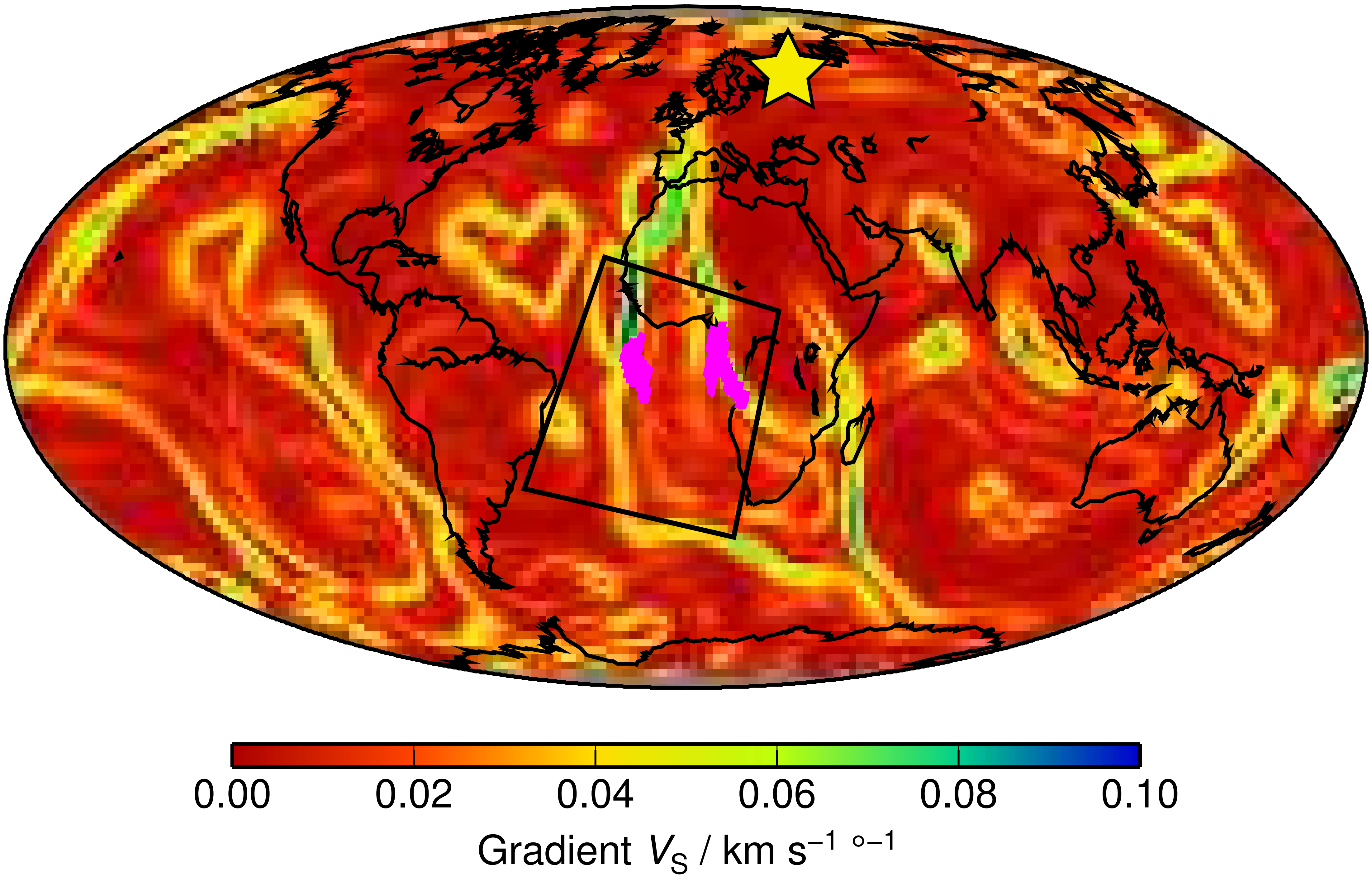
TC



‘Mapping’ with SKS

TCB ppv, paths to 3680 km radius, $|\nabla V_S|$ 400 km above CMB

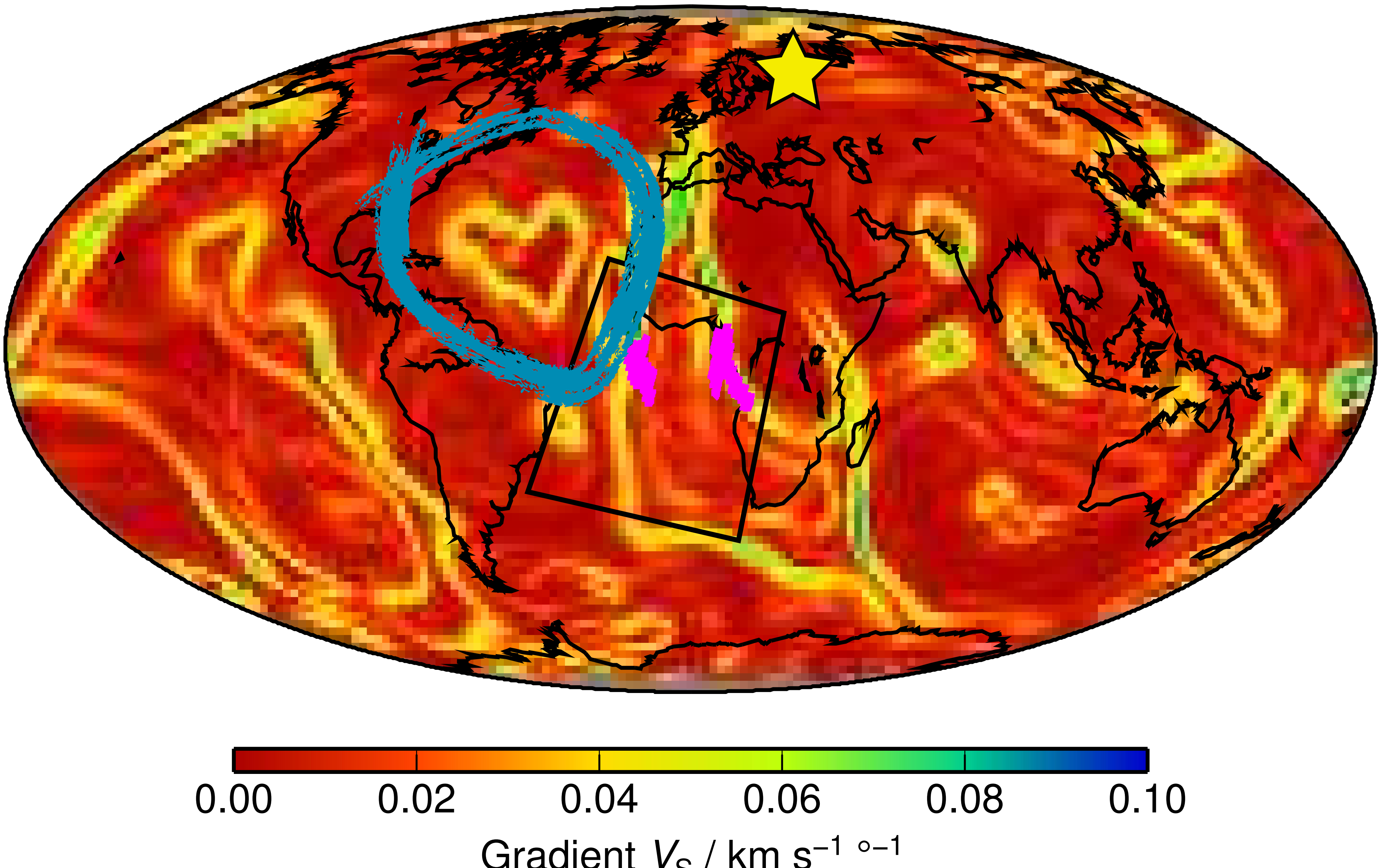
TC



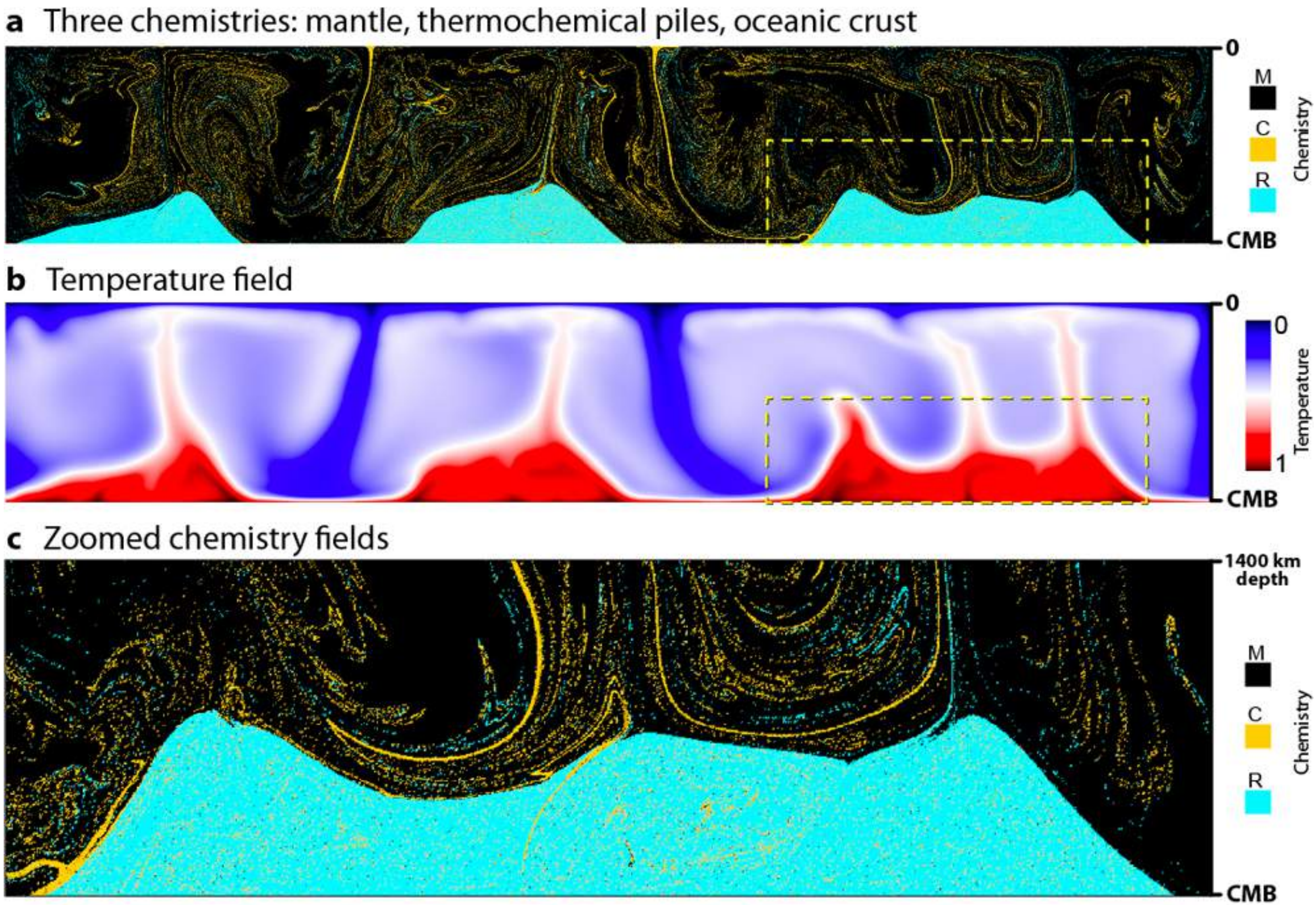
‘Mapping’ with SKS

TCB ppv, paths to 3680 km radius, $|\nabla V_S|$ 400 km above CMB

TC

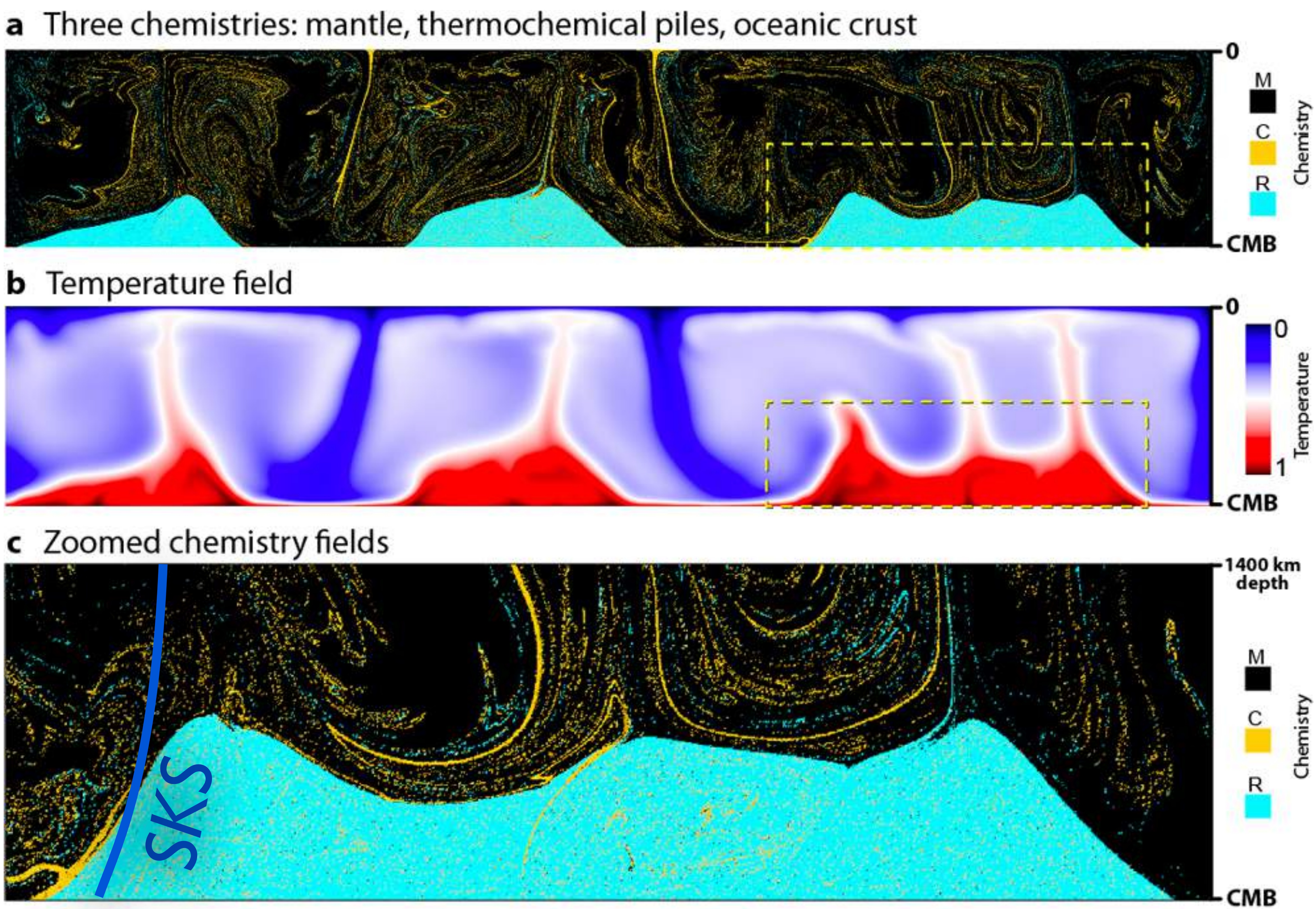


Pile morphology



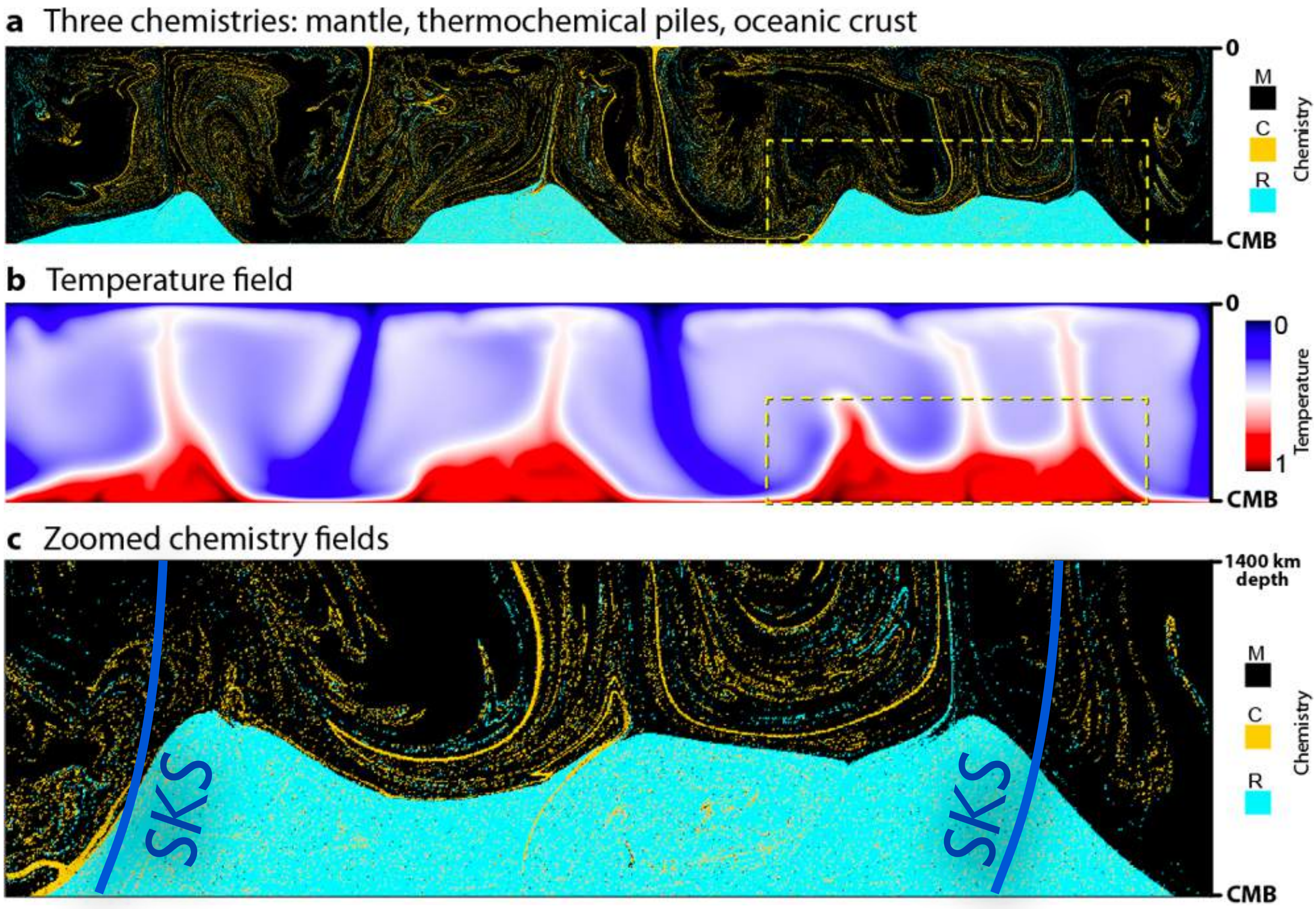
Garnero et al., Nature Geosci, 2016

Pile morphology



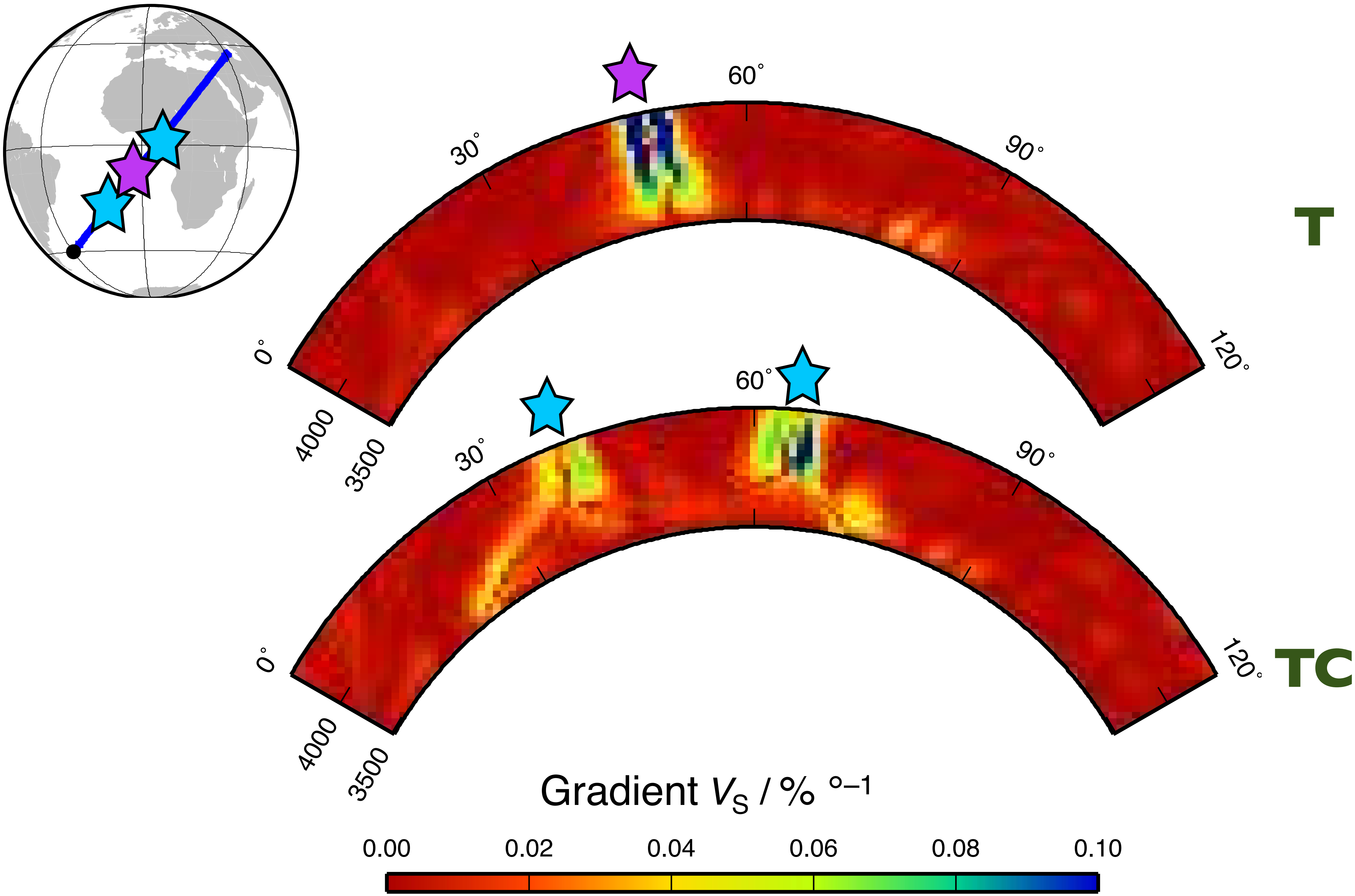
Garnero et al., Nature Geosci, 2016

Pile morphology

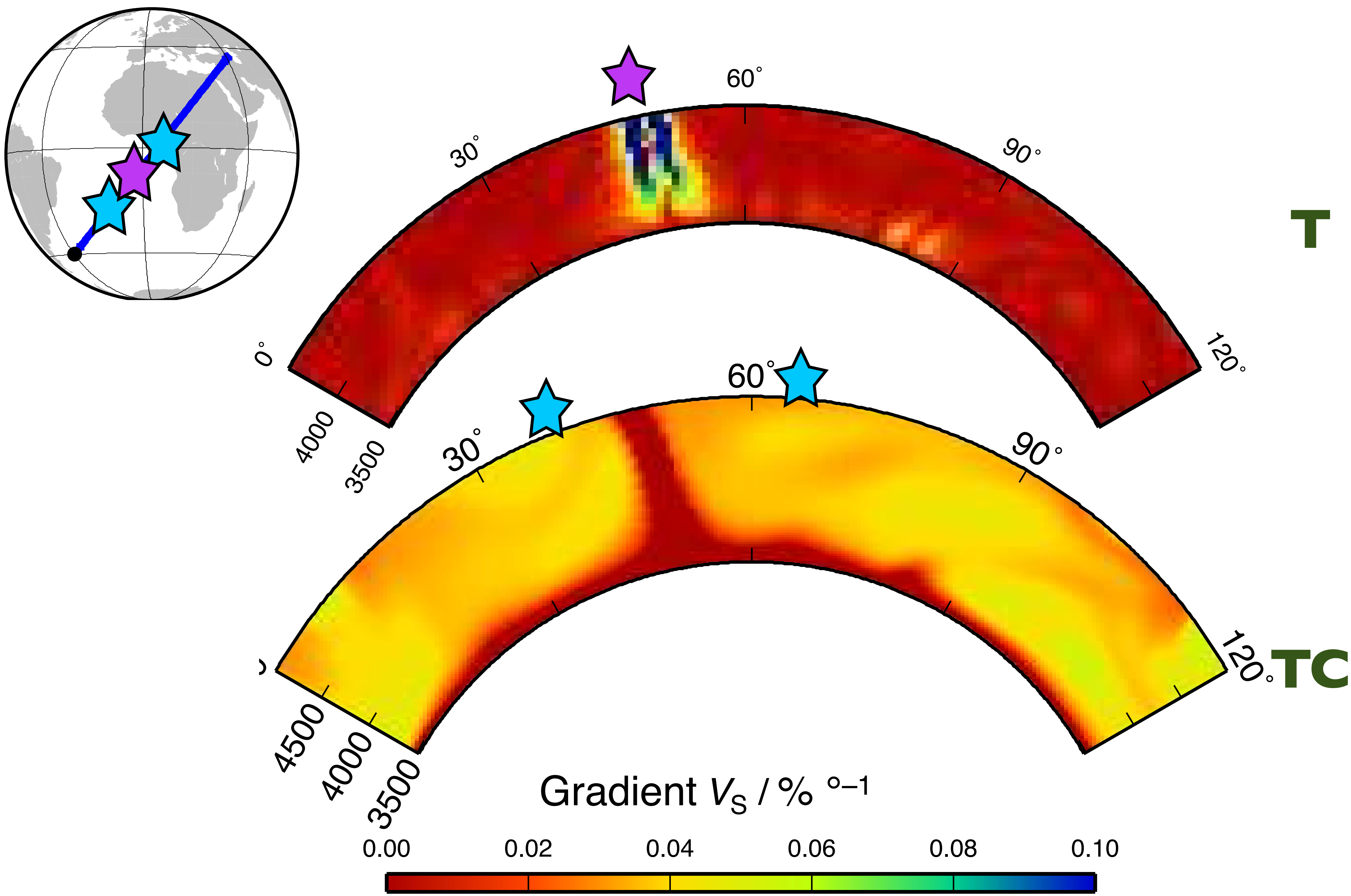


Garnero et al., Nature Geosci, 2016

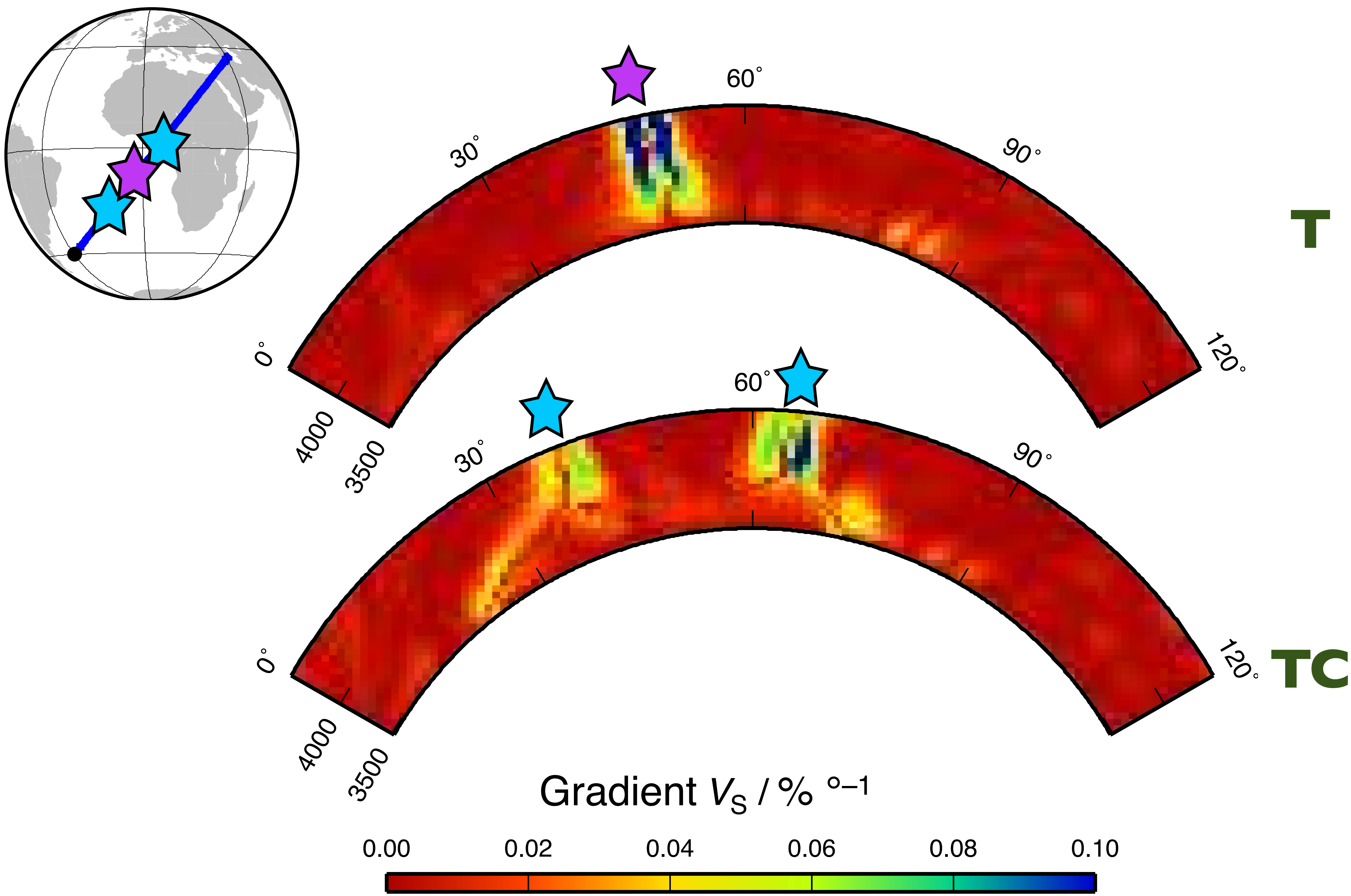
Lateral gradients (no ppv)



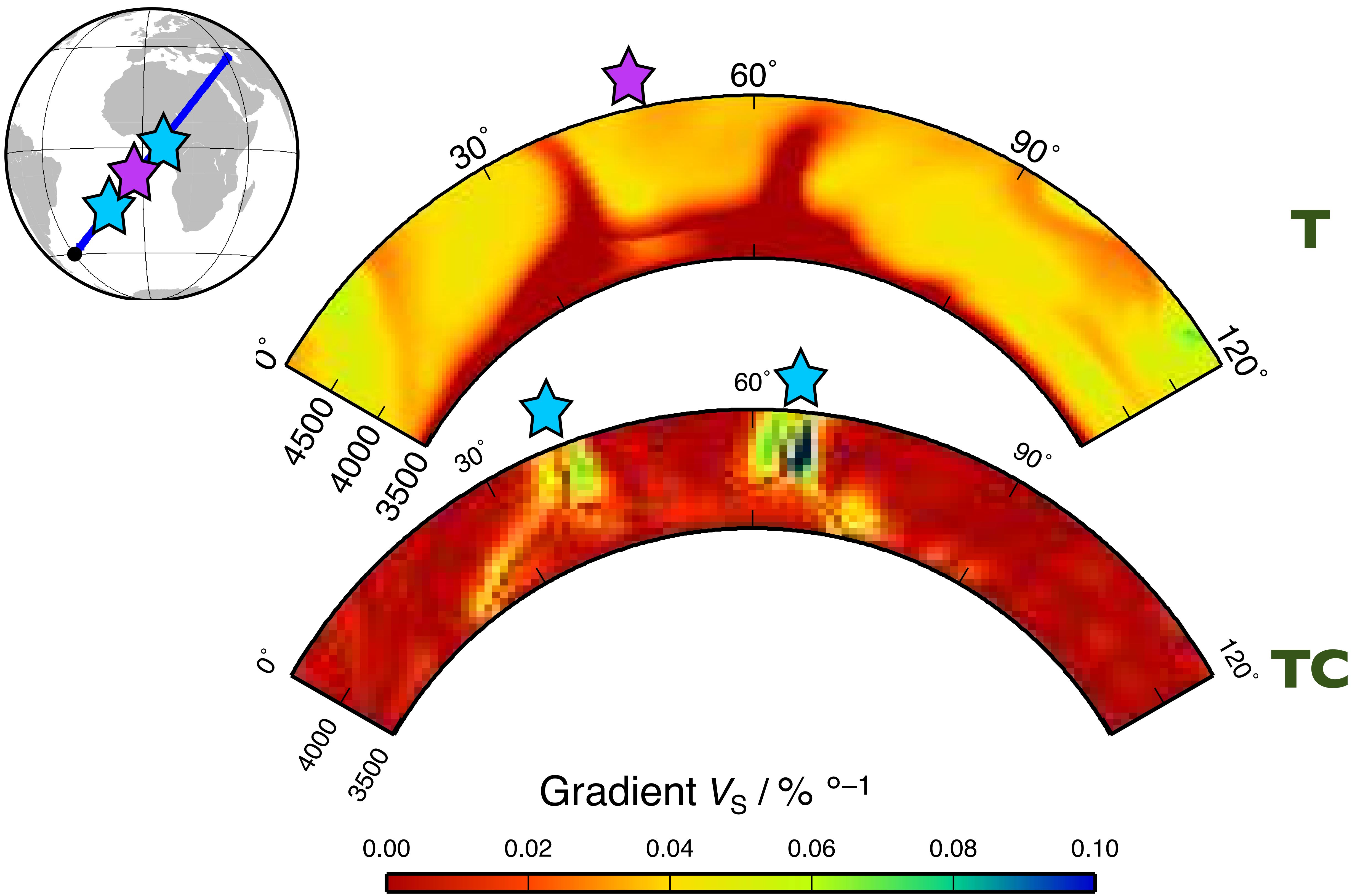
Lateral gradients (no ppv)



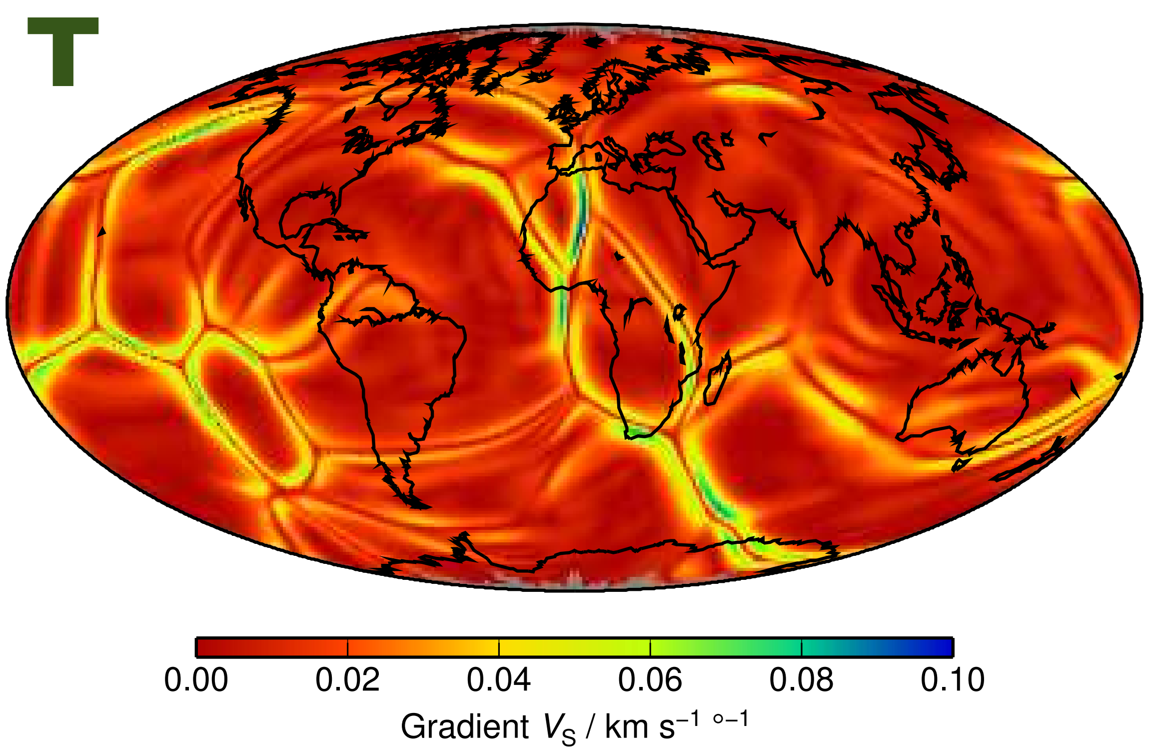
Lateral gradients (no ppv)

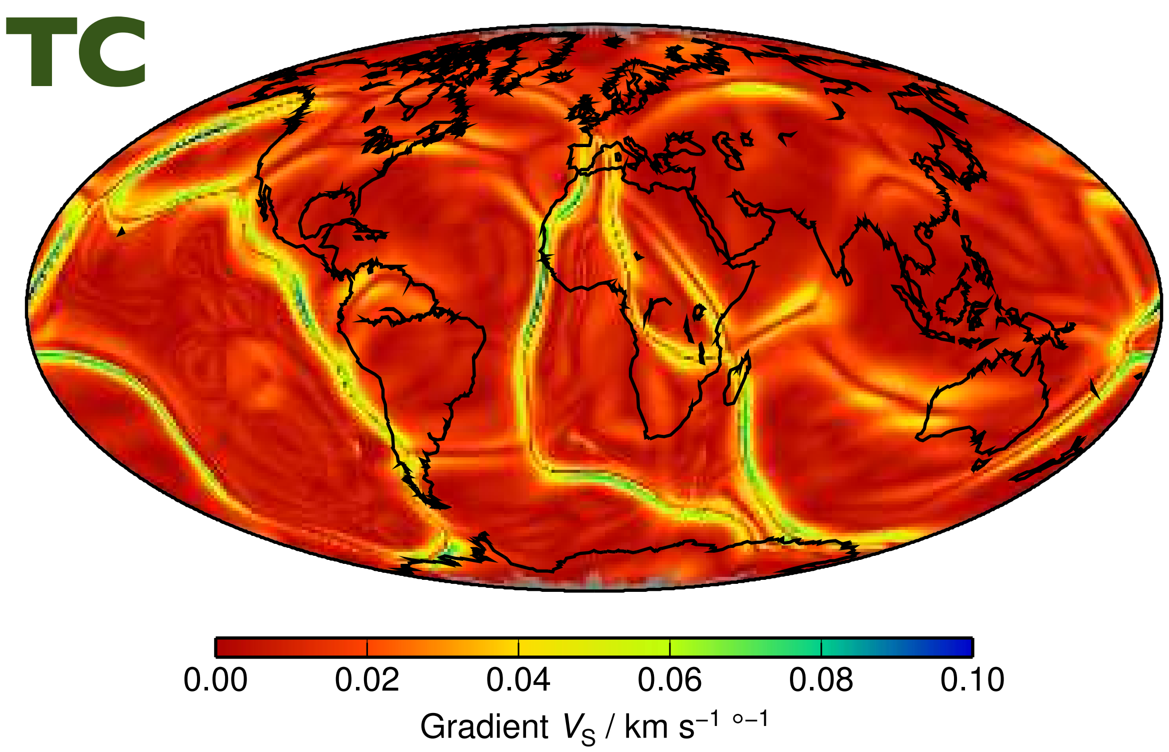


Lateral gradients (no ppv)



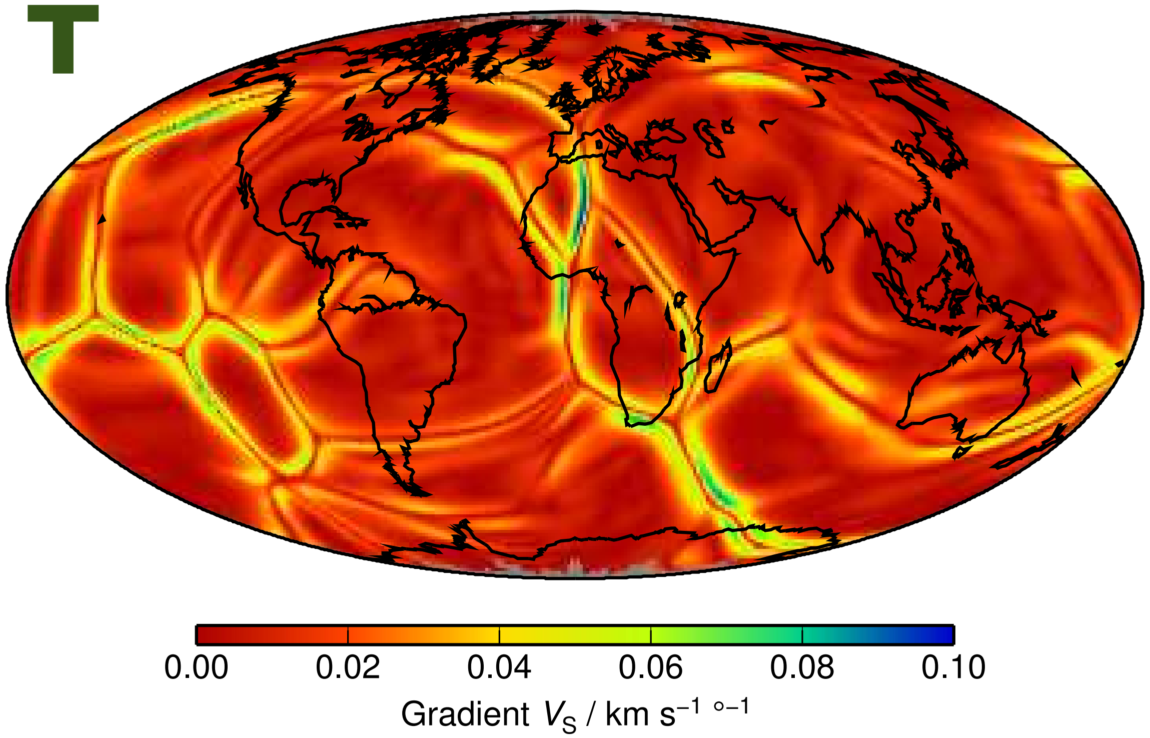
Do sharp gradients *have* to be chemical?

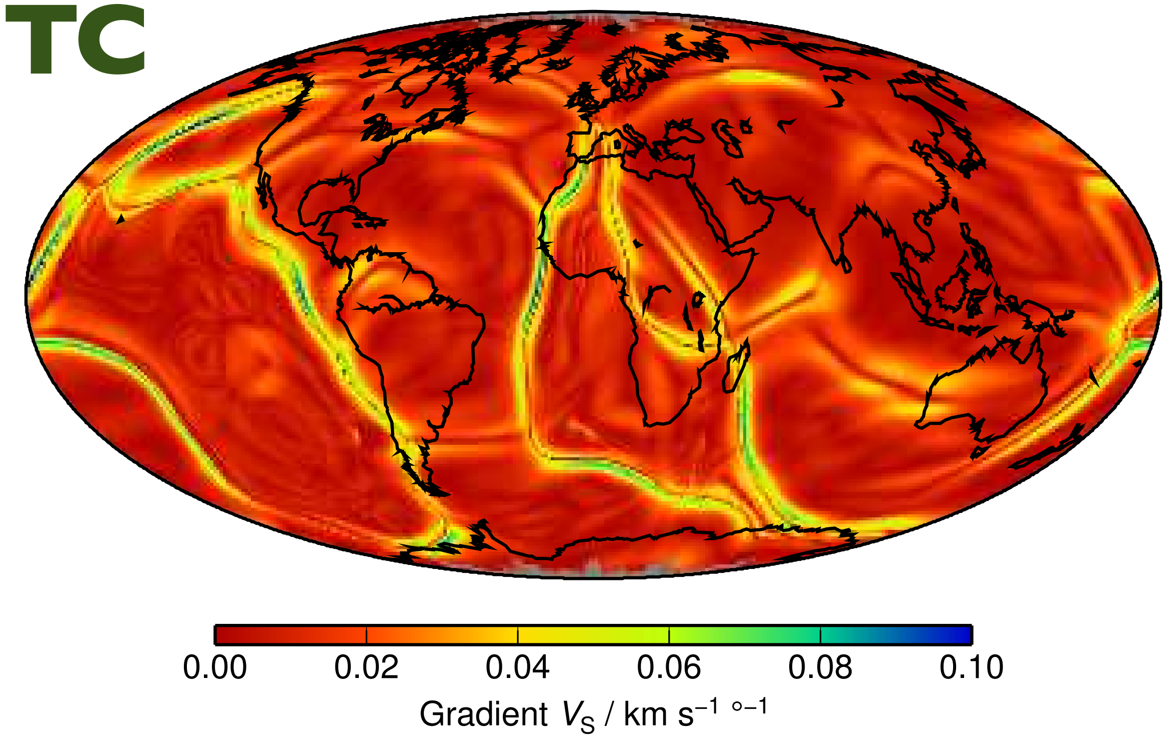




Do sharp gradients *have* to be chemical?

- Sharp gradients arise even in thermal models of convection

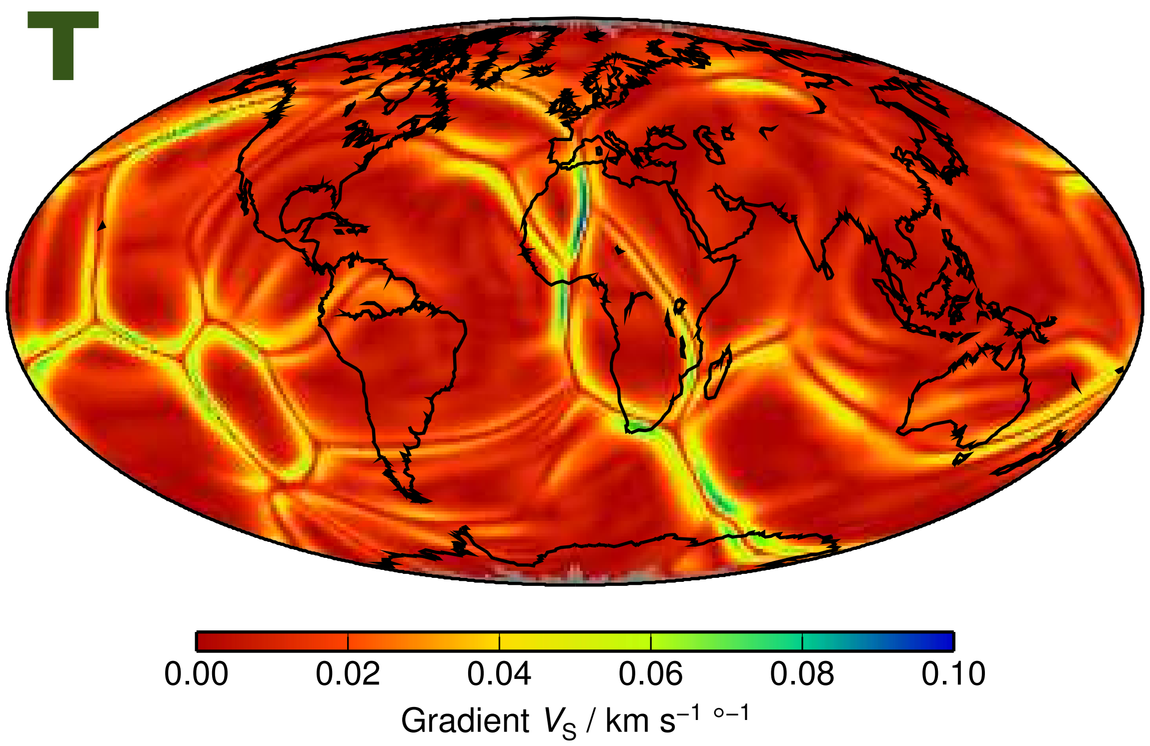




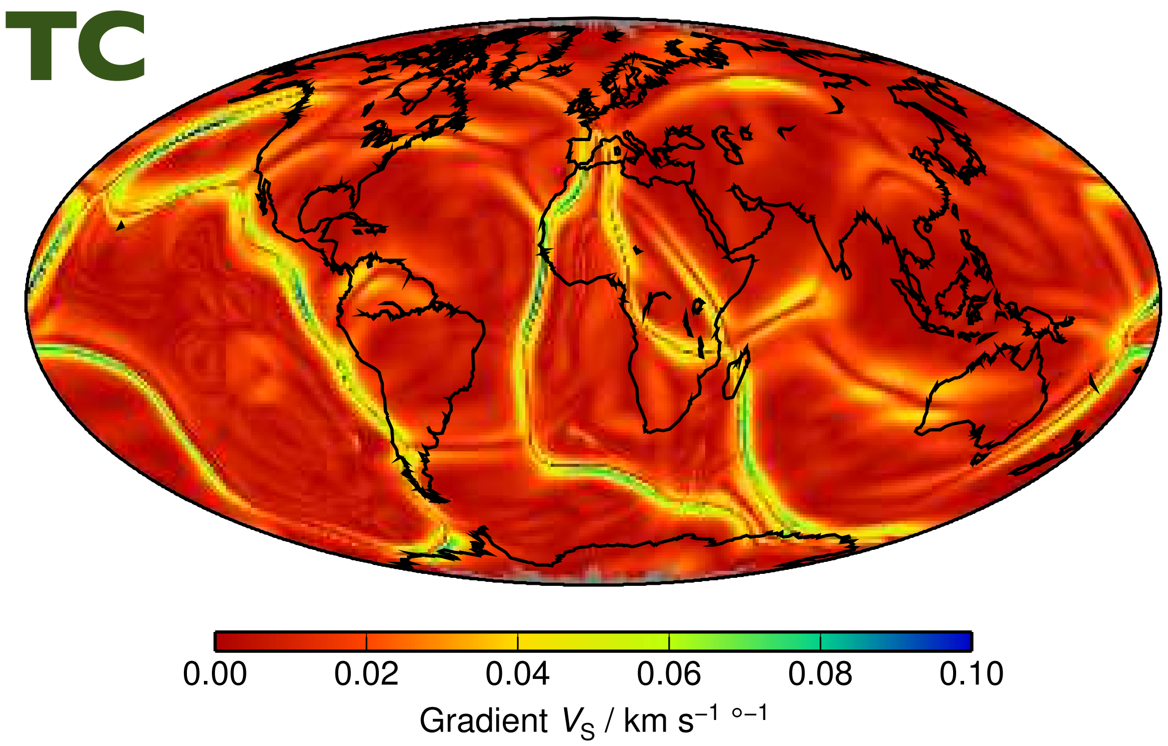
Do sharp gradients *have* to be chemical?

- Sharp gradients arise even in thermal models of convection
- Both T and TCB models lead to multipathing

T

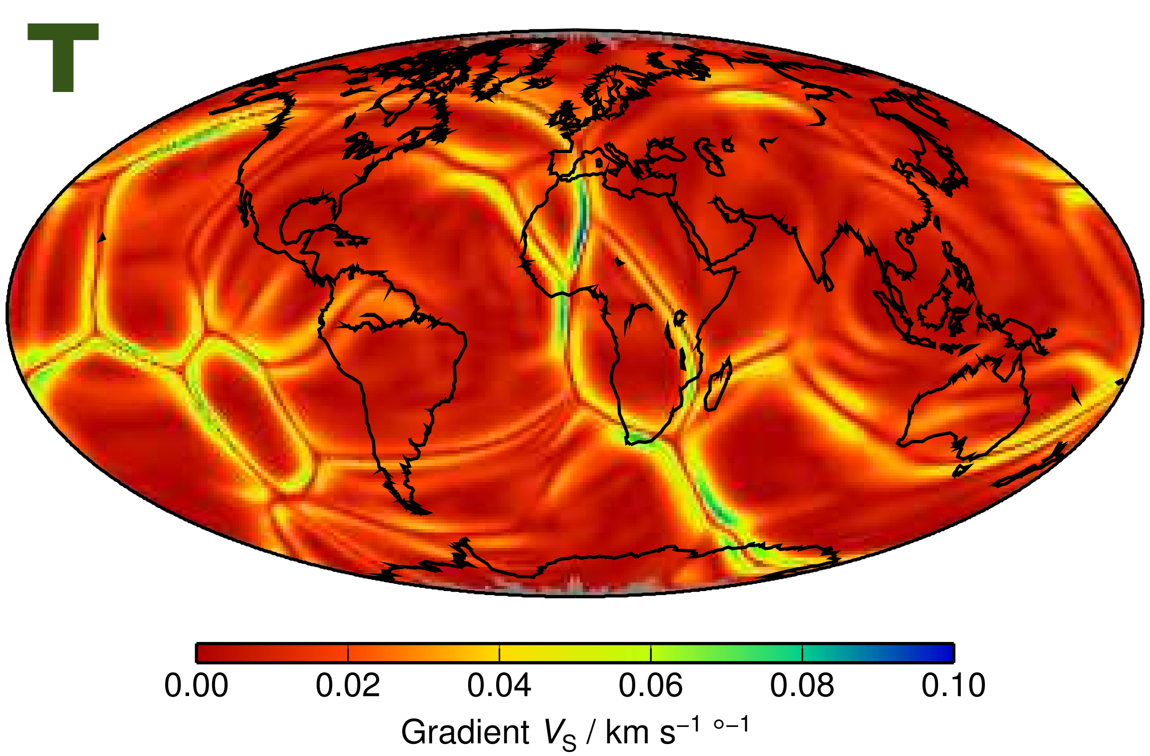


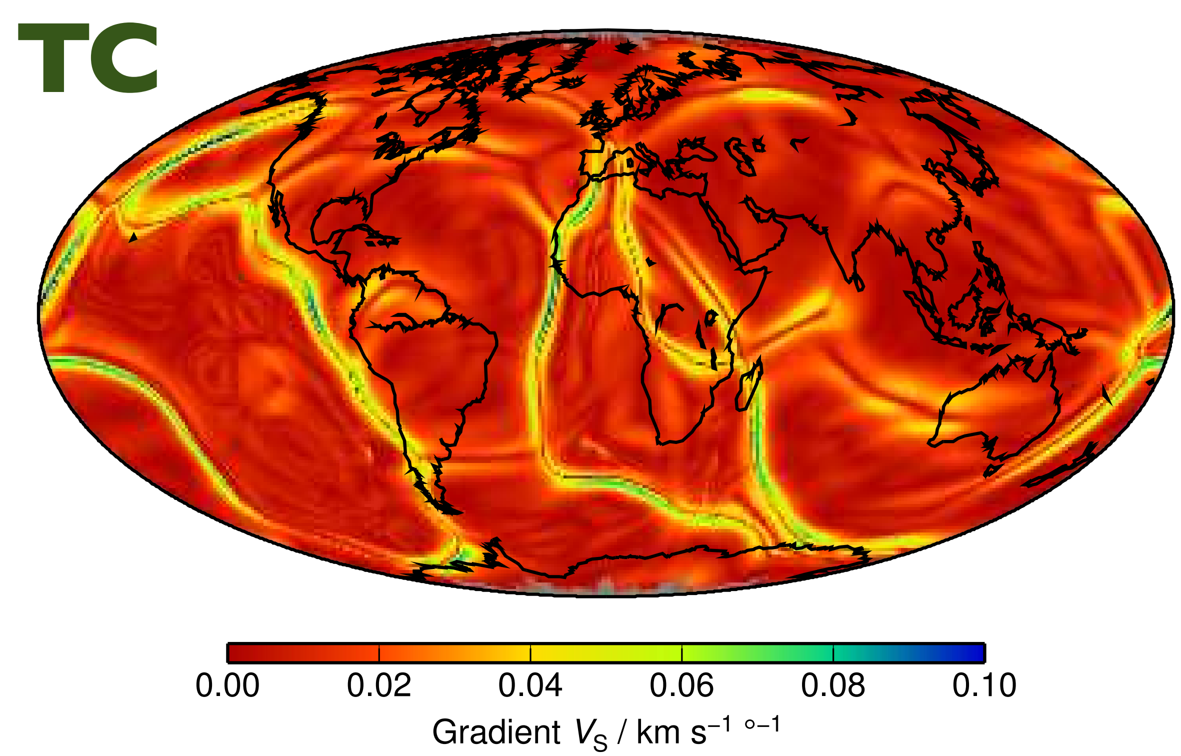
TC



Do sharp gradients *have* to be chemical?

- Sharp gradients arise even in thermal models of convection
- Both T and TCB models lead to multipathing
- Sharp sides may not represent what we think they do



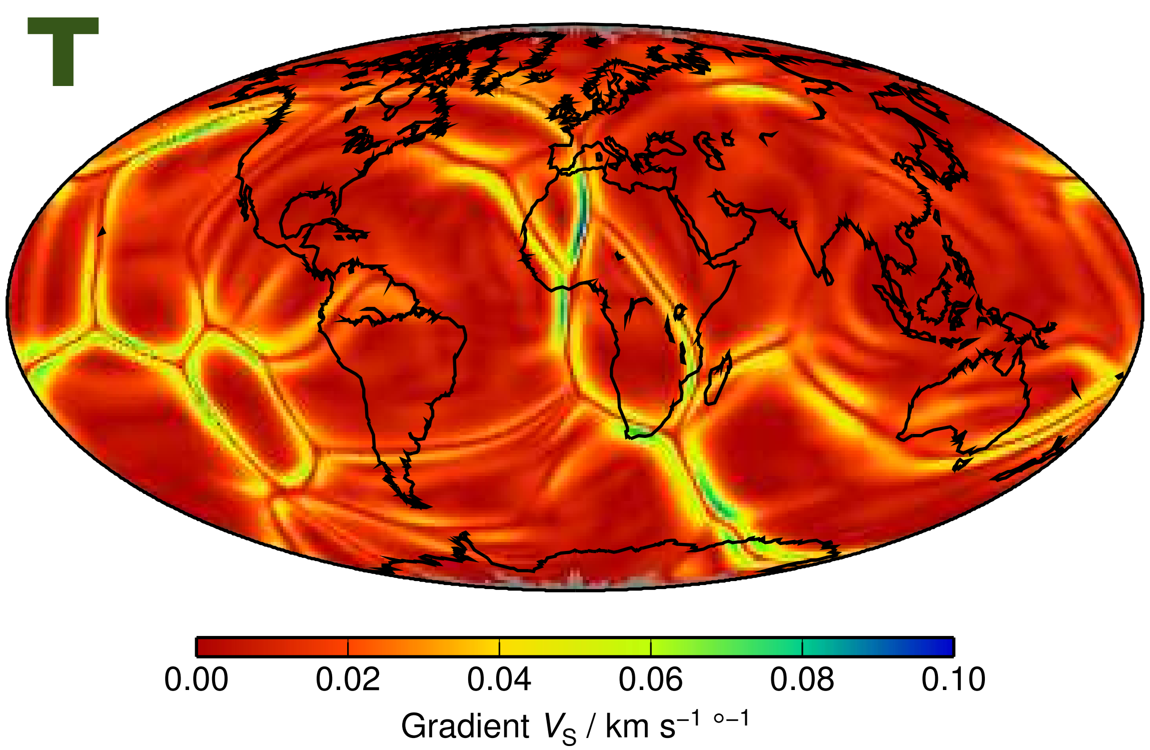


Do sharp gradients *have* to be chemical?

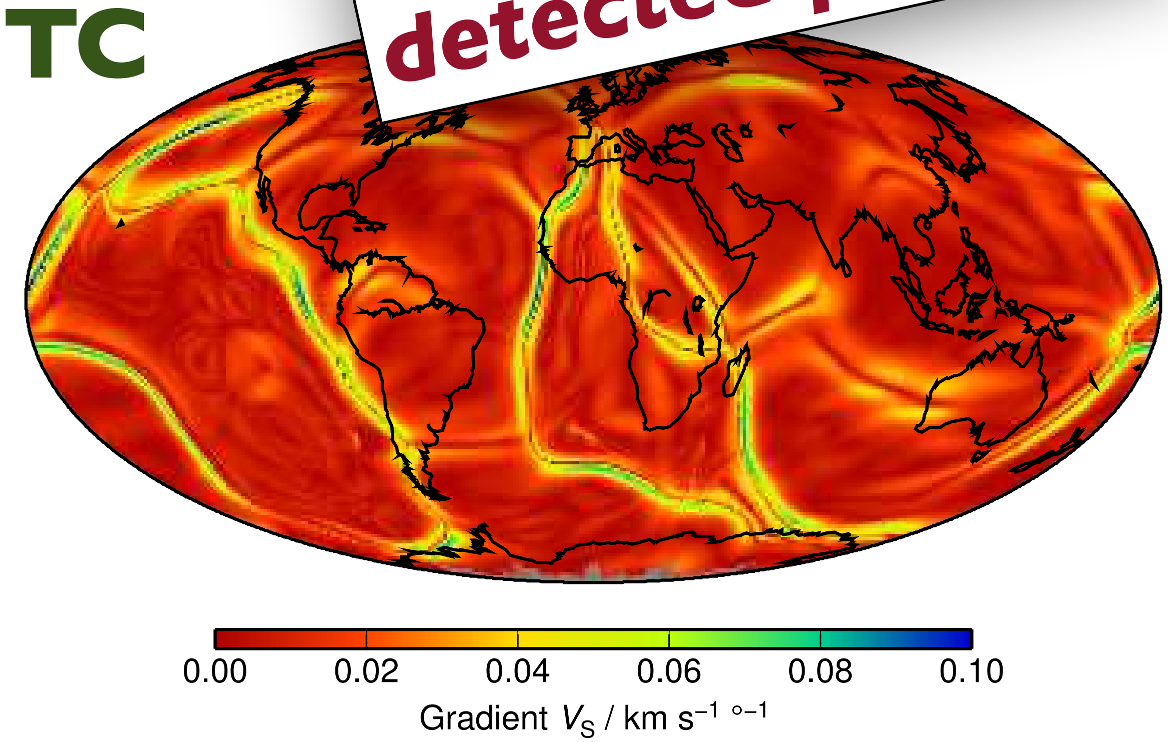
- Sharp gradients arise even in thermal models of convection
- Both T and TCB models lead to multipathing
- Sharp sides may not represent what we think they do

Have we already detected plumes?

T

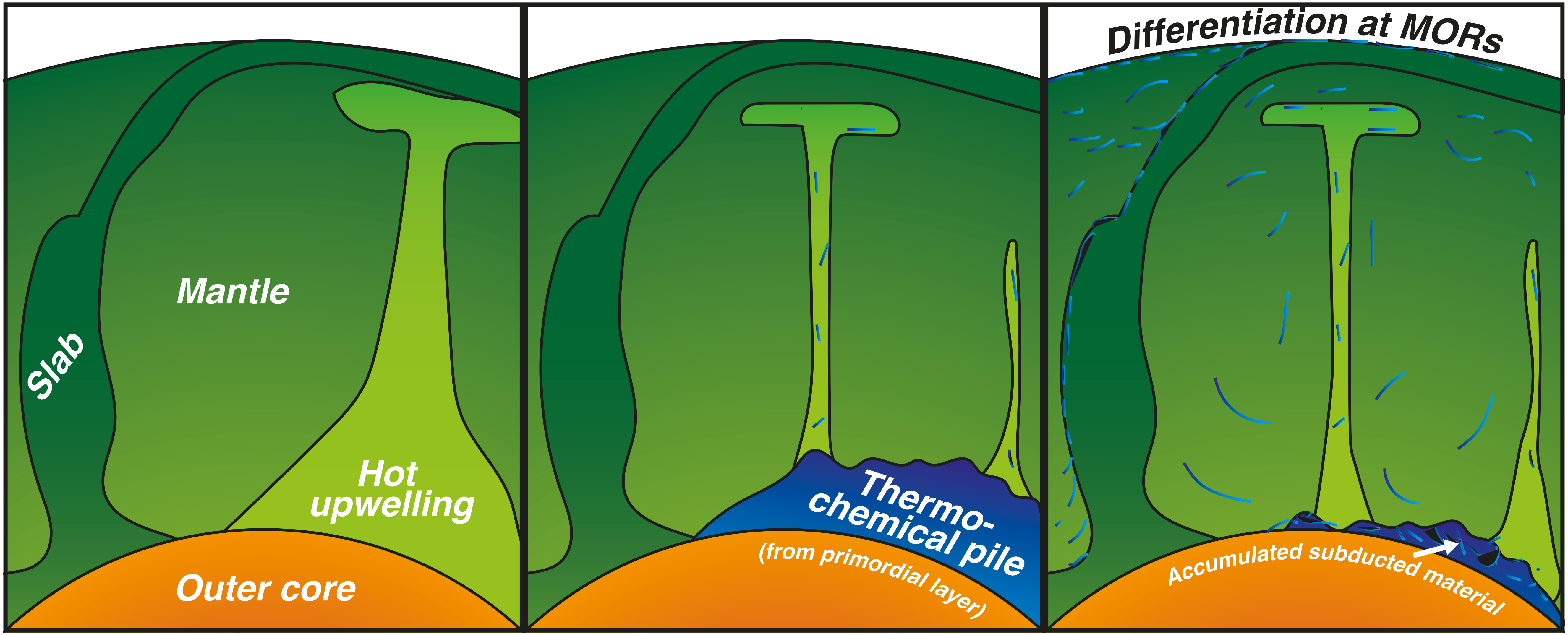


TC



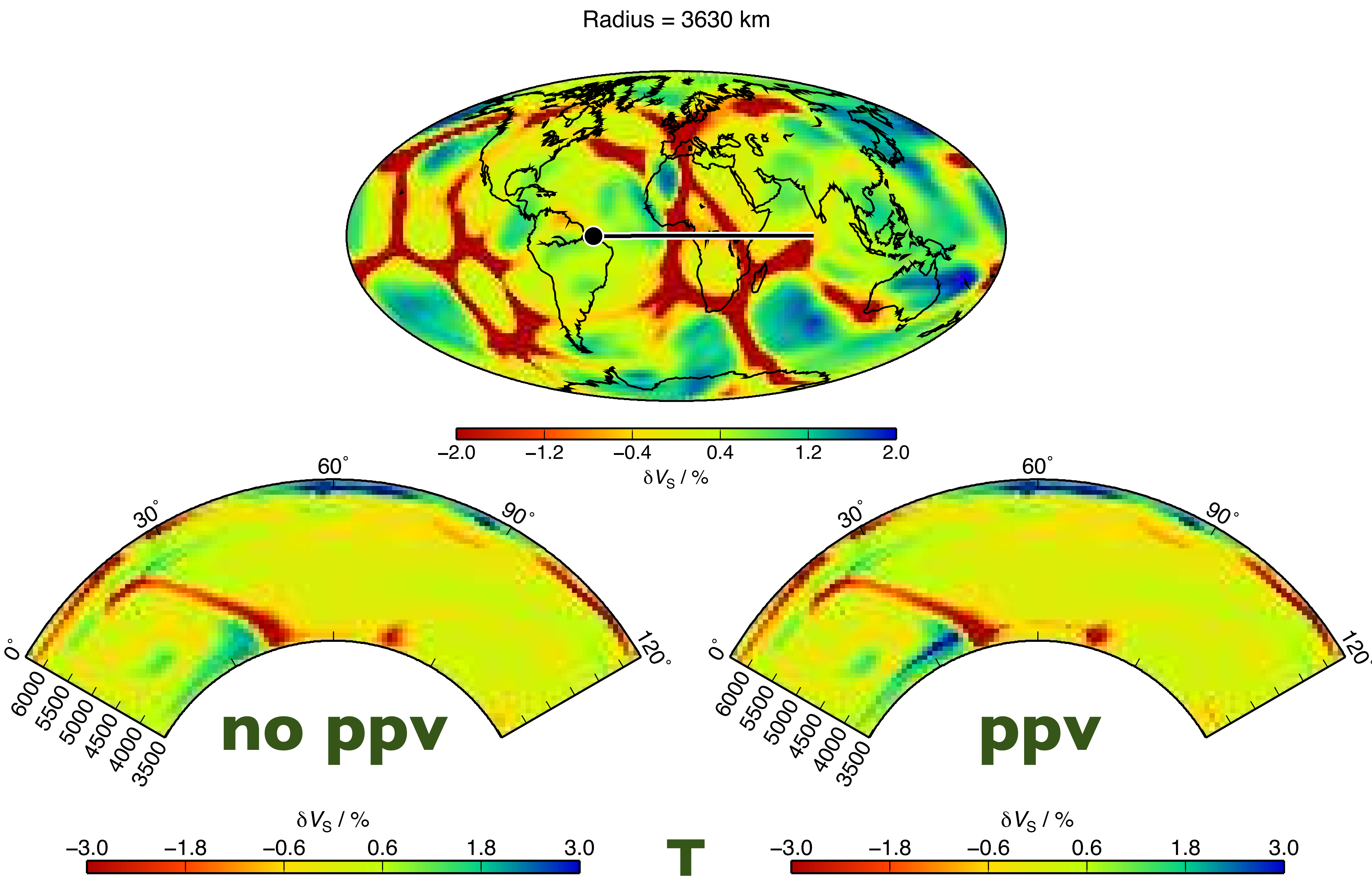
finni

Next



Mantle
Slab
Hot upwelling
Outer core
Thermo-chemical pile
(from primordial layer)
Differentiation at MORs
Accumulated subducted material

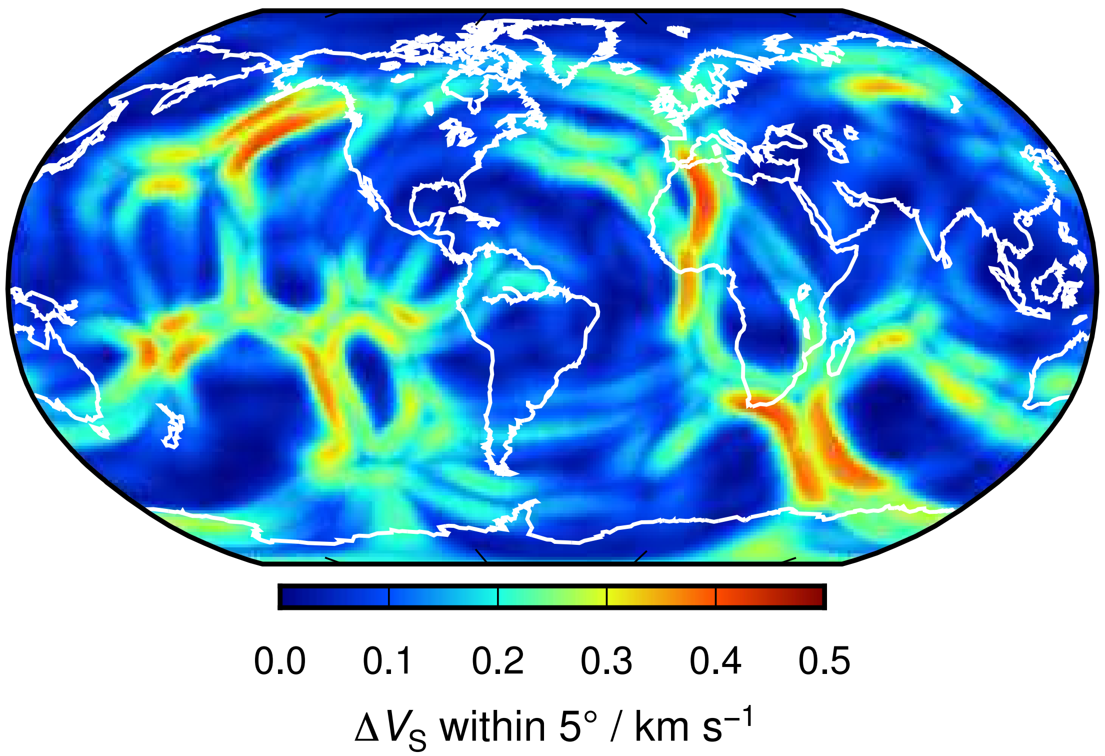
Effect of ppv



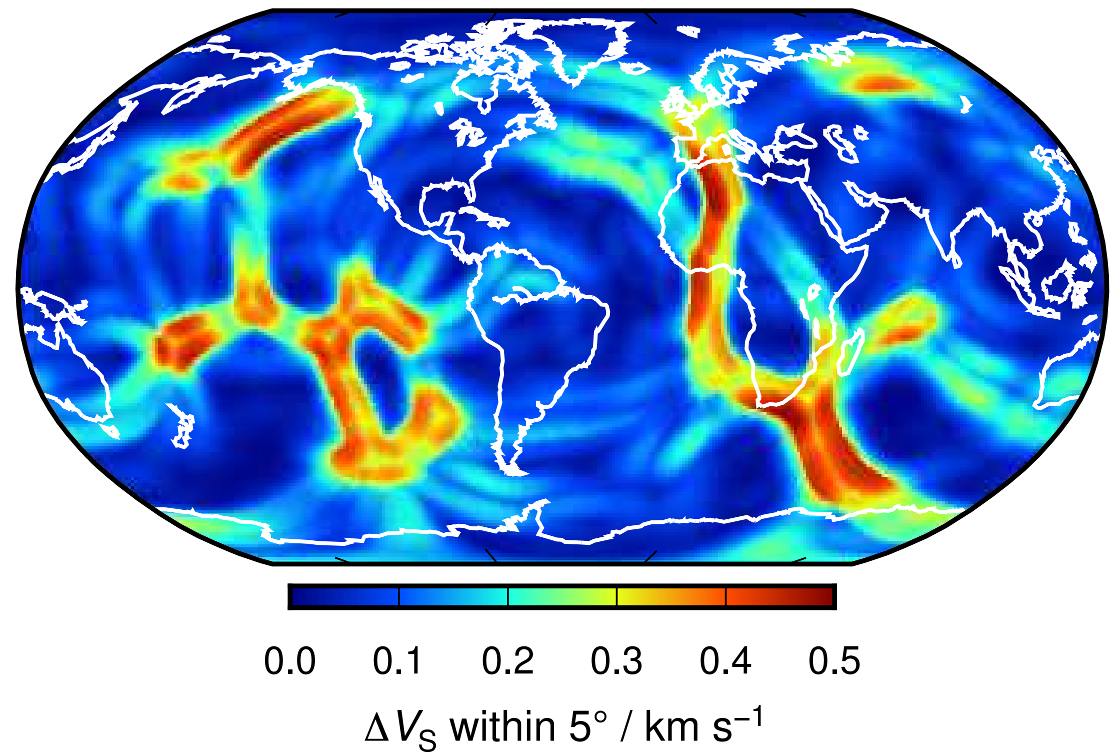
Nowacki et al., in prep.

Ranges in velocities

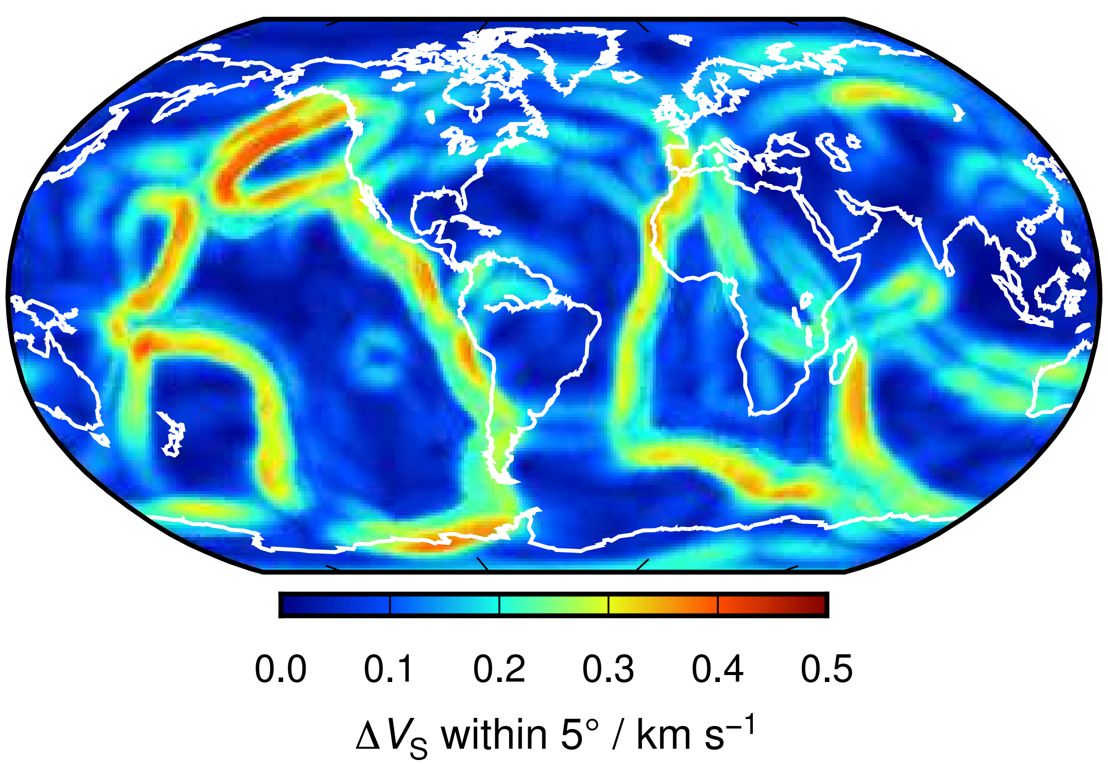
T no ppv, 100 km above CMB



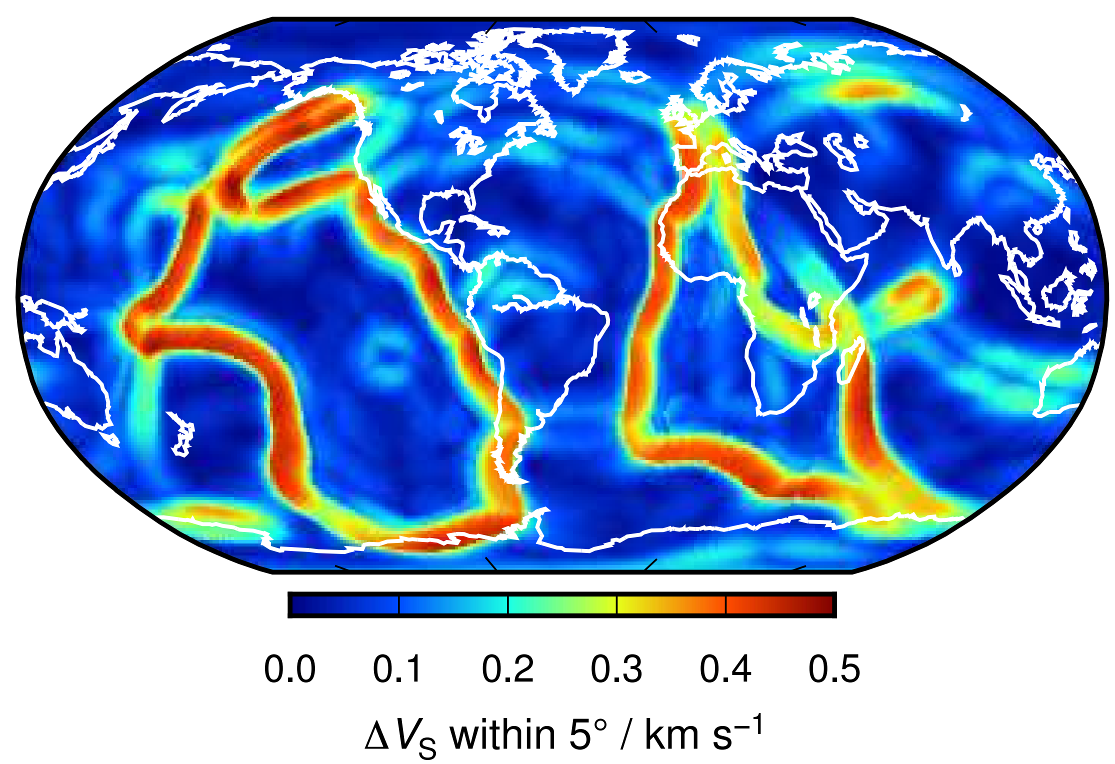
T ppv, 100 km above CMB



TCB no ppv, 100 km above CMB

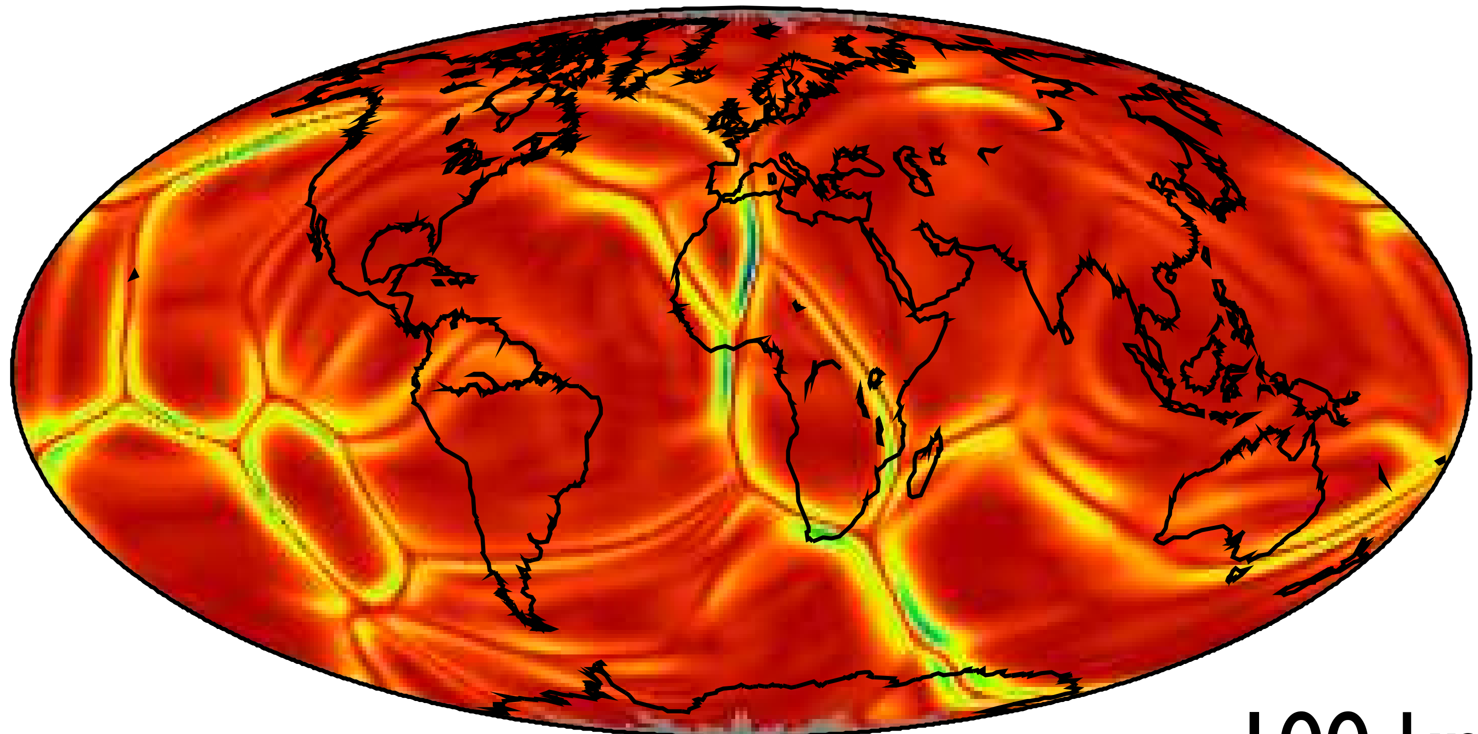


TCB ppv, 100 km above CMB



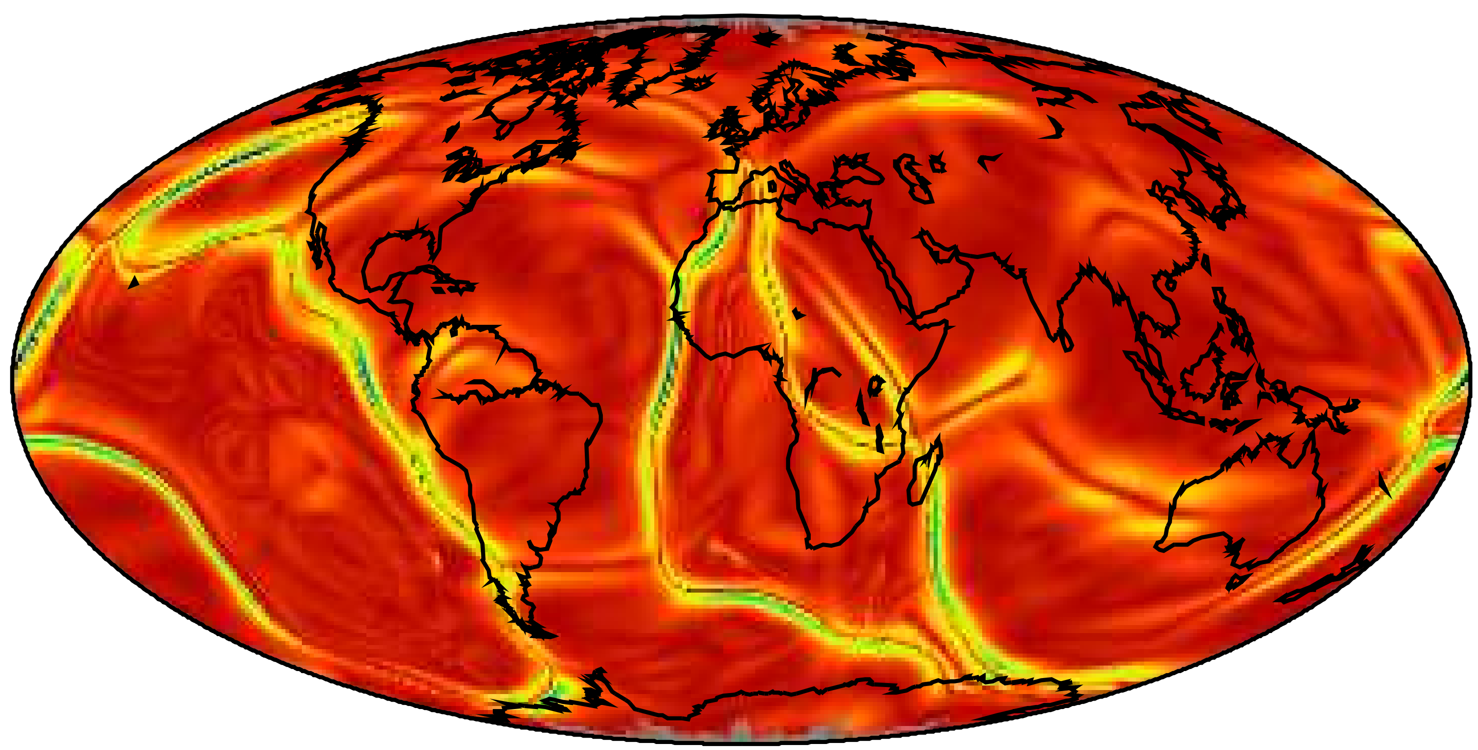
Lateral gradients: models (no ppv)

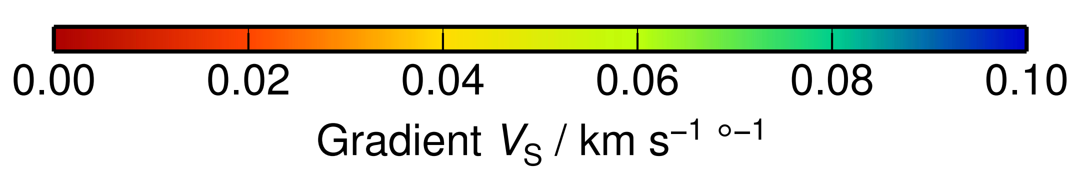
T



100 km above CMB

TC



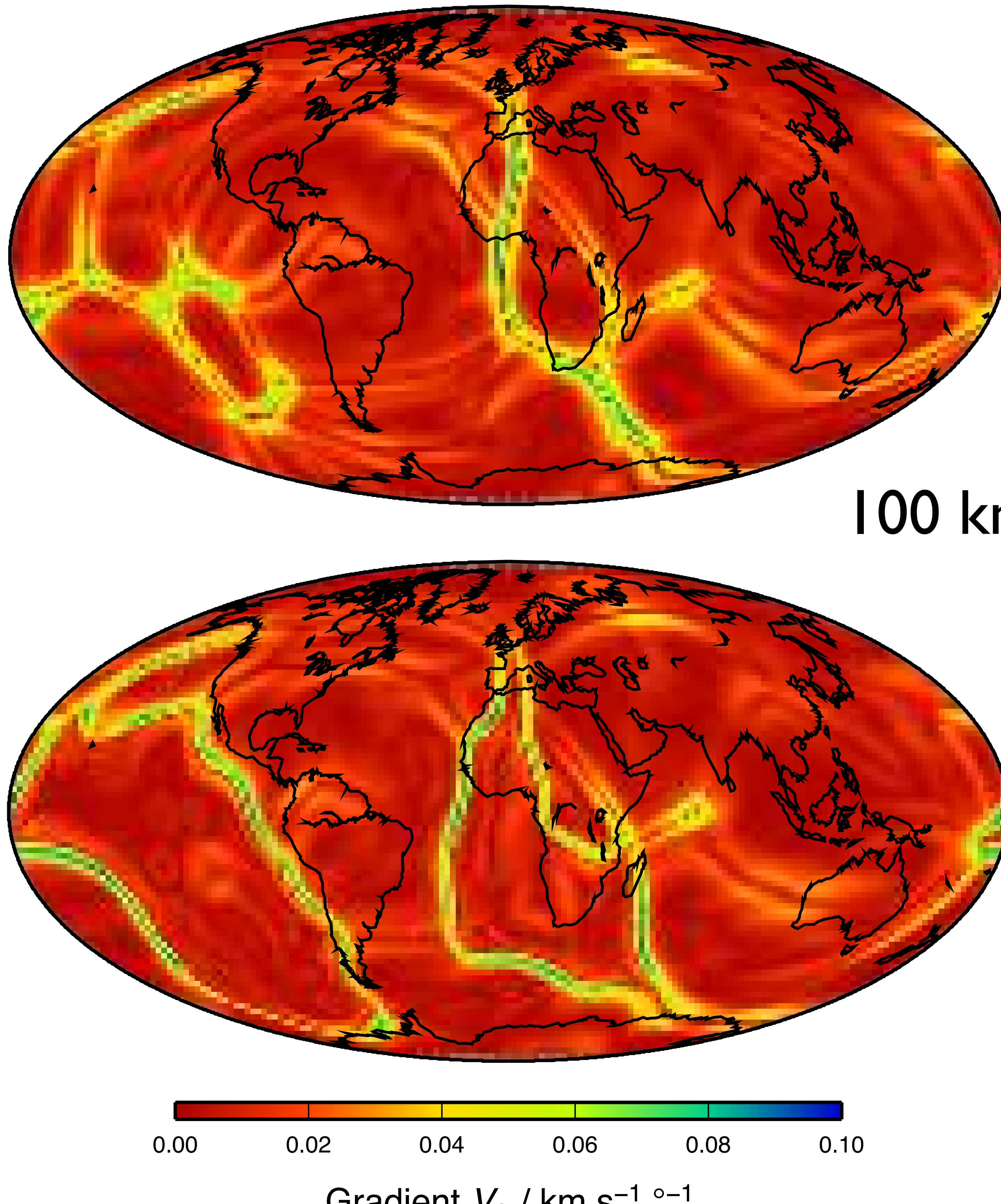


Nowacki et al., in prep.

Lateral gradients: models (with ppv)

T

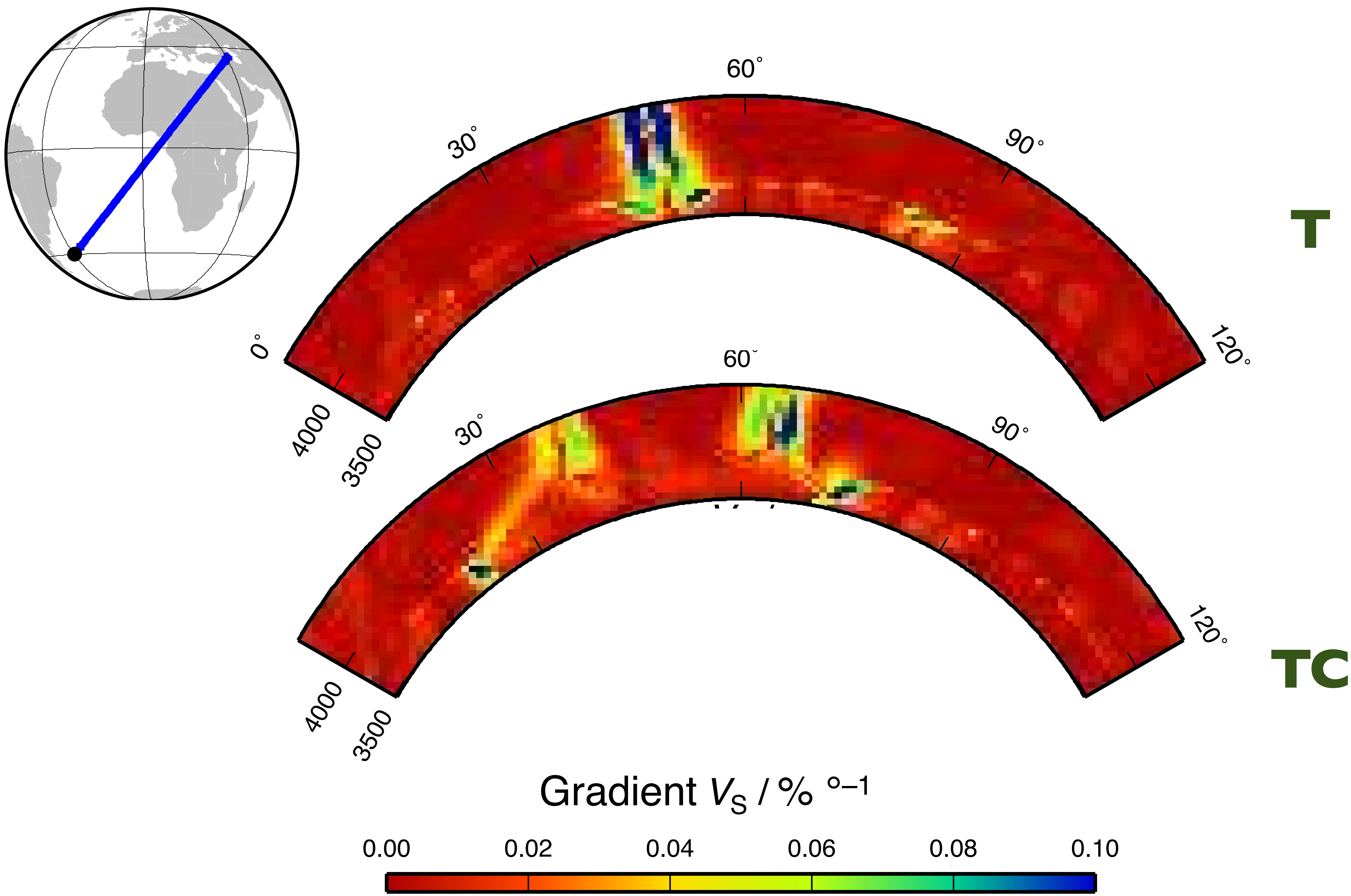
TC



100 km above CMB

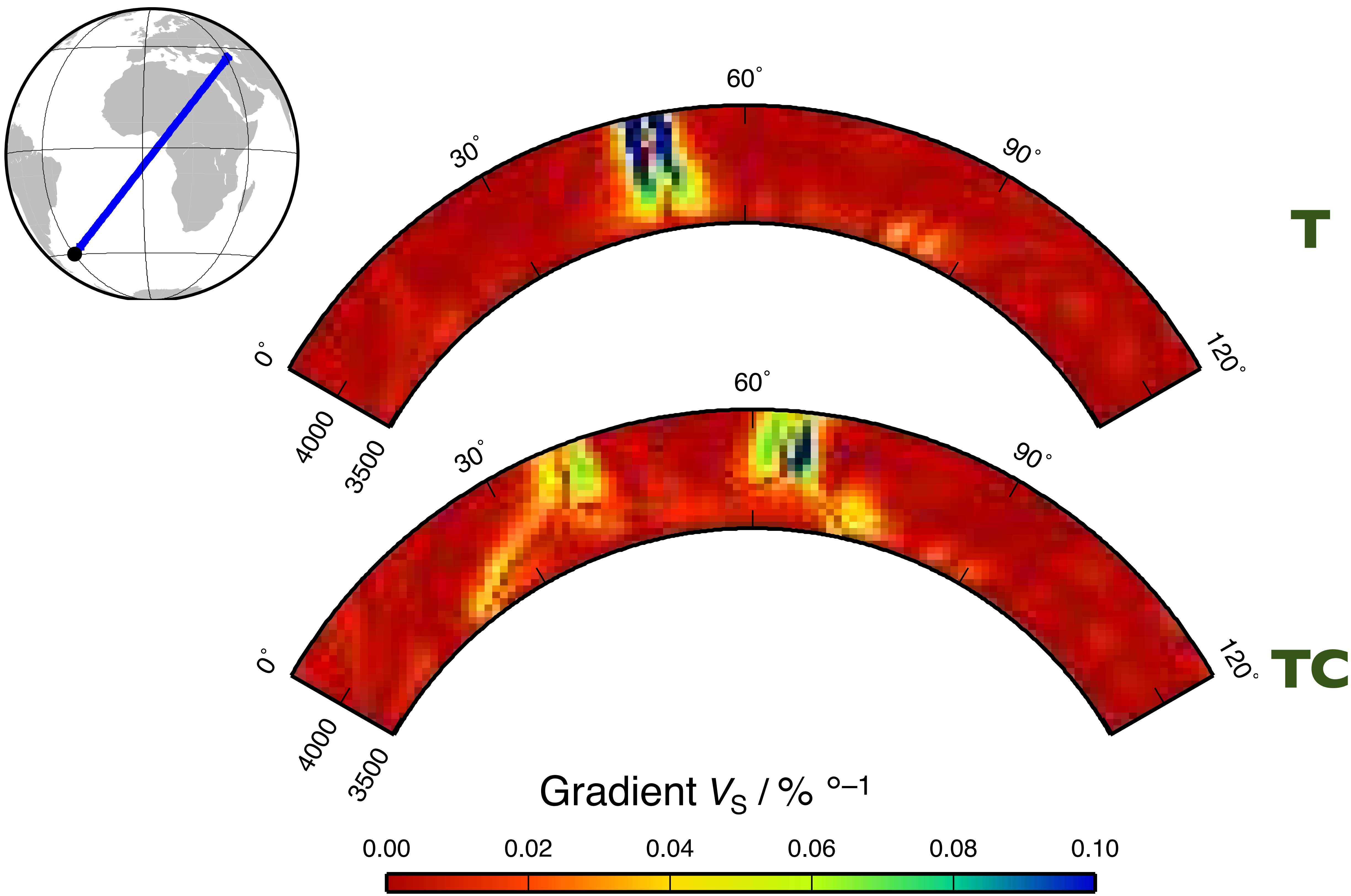
Nowacki et al., in prep.

Lateral gradients (ppv)



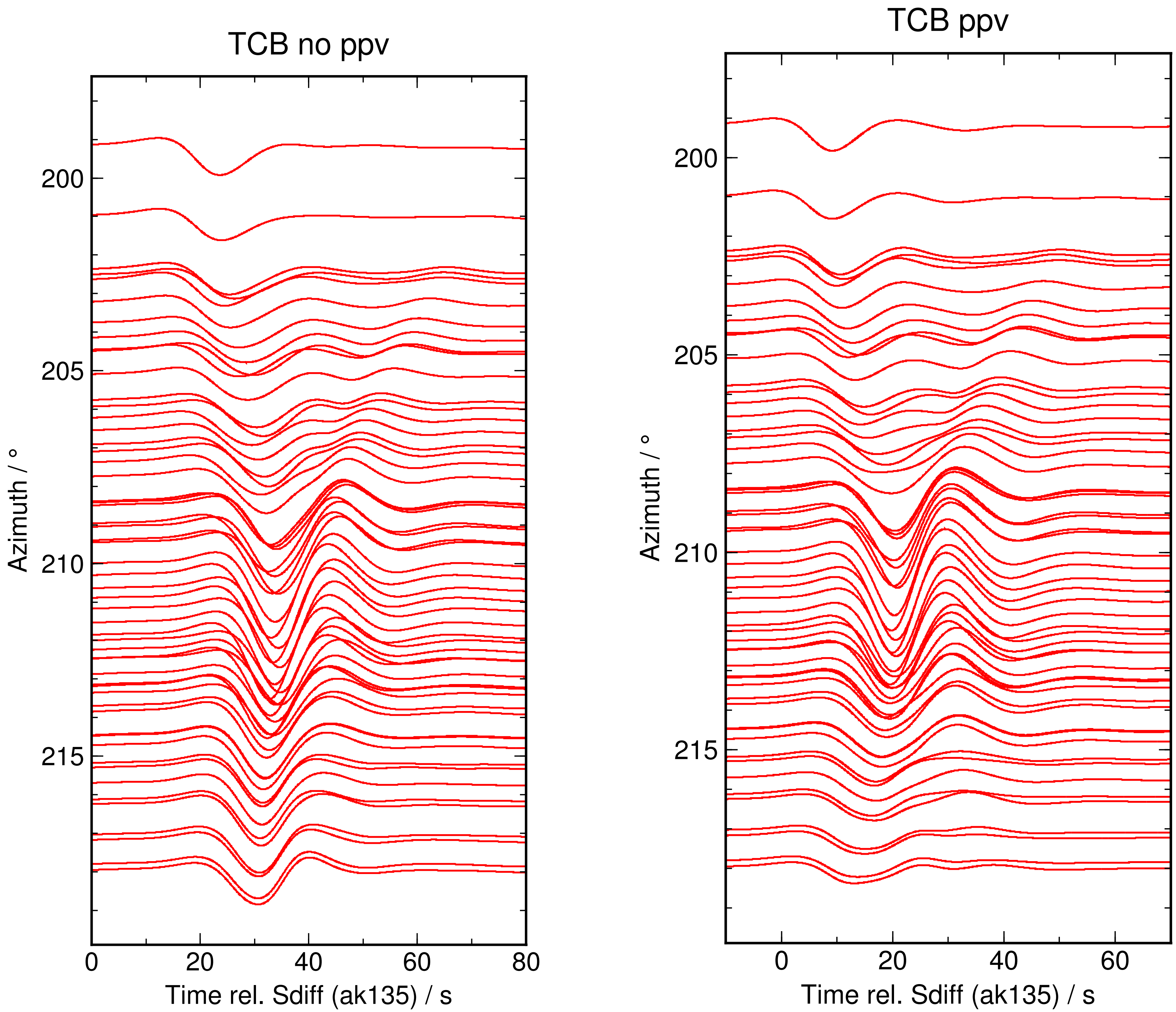
Reference

Lateral gradients (no ppv)



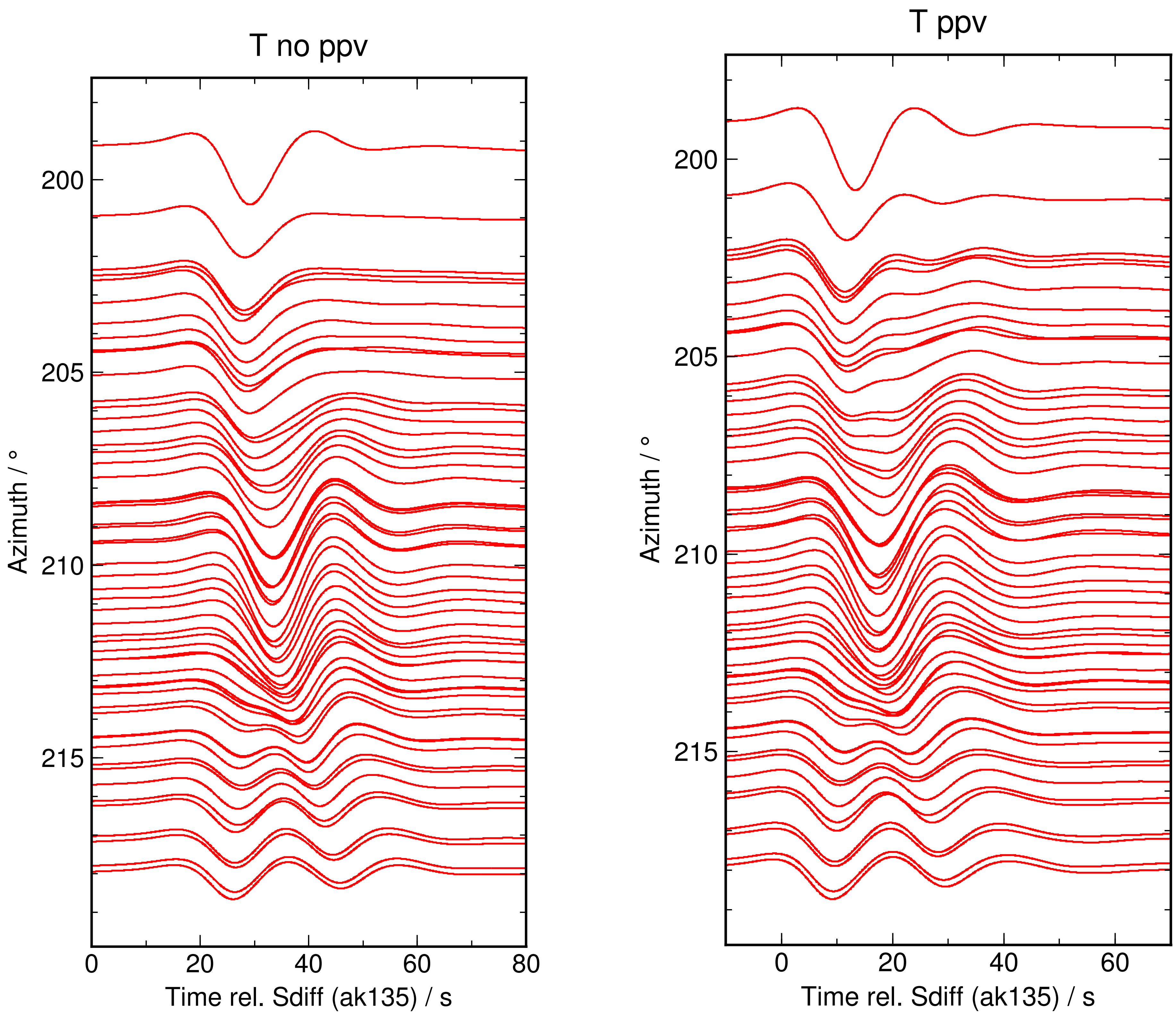
Reference

Effect of ppv



Nowacki et al., in prep.

Effect of ppv



Nowacki et al., in prep.