The effects of seismic anisotropy on S-wave travel-time tomography: the problem of apparent anomalies and possible solutions

Francesco Rappisi[1], Brandon P. VanderBeek[1], & Manuele Faccenda[1]

[1]Università di Padova

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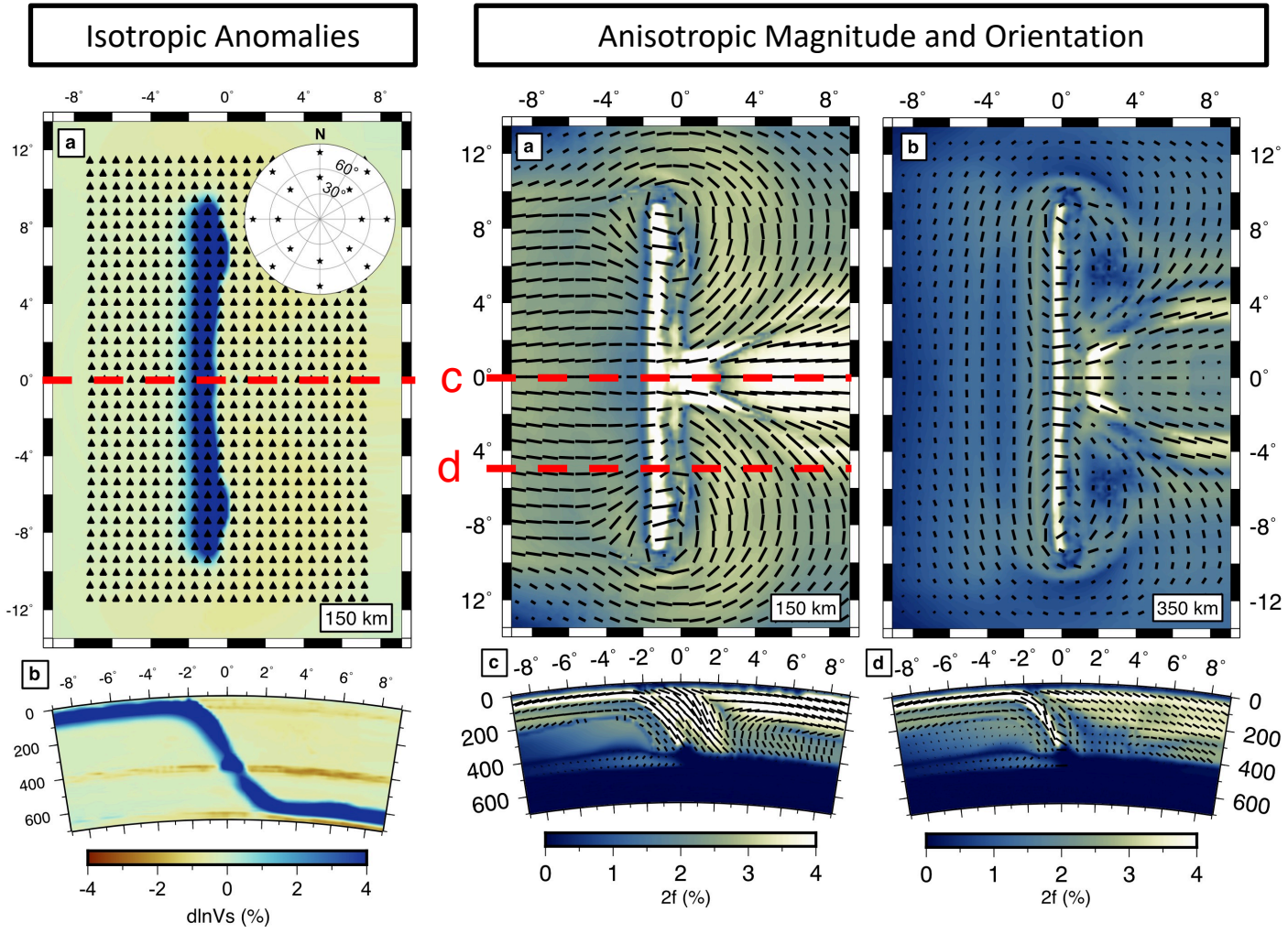
Motivation

- Contradictory assumptions regarding analysis of teleseismic wavefield
  - Shear wave splitting used to infer anisotropic structure
  - But we often ignore anisotropy in constructing tomographic models
- Neglecting anisotropy in teleseismic P-wave tomography generates significant artefacts
  - E.g., Blackman & Kendall, 1997; Sieminski et al., 2007; Lloyde & van der Lee, 2008; Bezada et al., 2016; VanderBeek & Faccenda, 2021
- Nature of imaging artefacts is less well understood for S-wave imaging
  - Analysis is complicated by effects of shear wave splitting
- Here we perform synthetic tomography experiments using an anisotropic geodynamic model of subduction
  - Significant anisotropy artefacts are observed
  - We find inversion strategies to minimize these artefacts and recover anisotropic information

Synthetic Subduction Zone Model and Seismic Data

Realistic synthetic dataset is independent from inversion algorithm

- Hexagonally anisotropic elastic model from geodynamic model of subduction (Faccenda, 2014)
- Model teleseismic wavefield with SPECFEM + AxiSEM (includes P, S, and SKS phases; Monteiller & Long, 2013; Nissen-Meyer et al., 2014). Dominant period = 15 s
- 770 receivers spaced 75 km apart record teleseismic wavefield from 16 sources evenly distributed in back azimuth



Colormap Credit: Crameri, 2018

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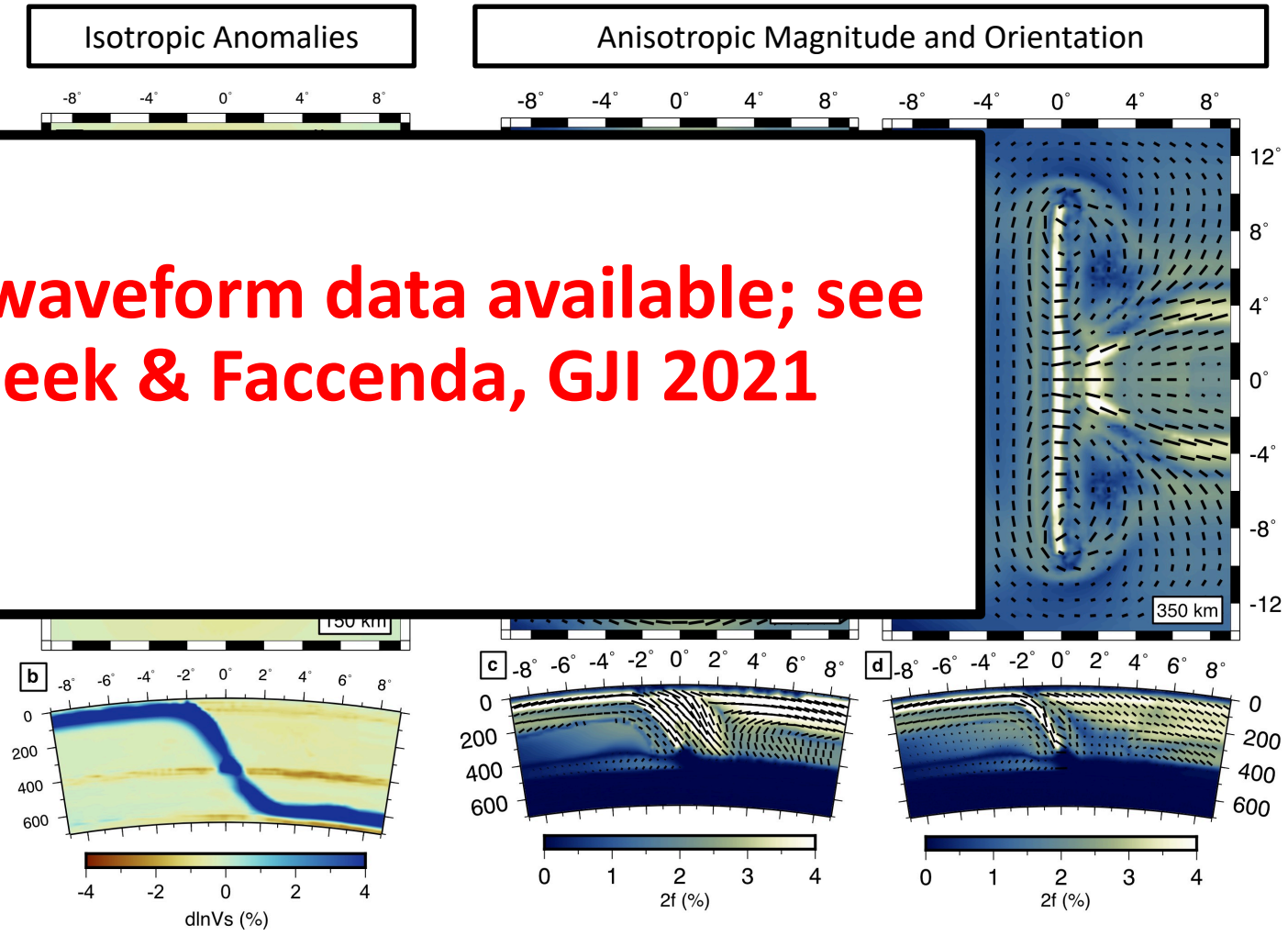
All seismic waveform data available; see VanderBeek & Faccenda, GJI 2021



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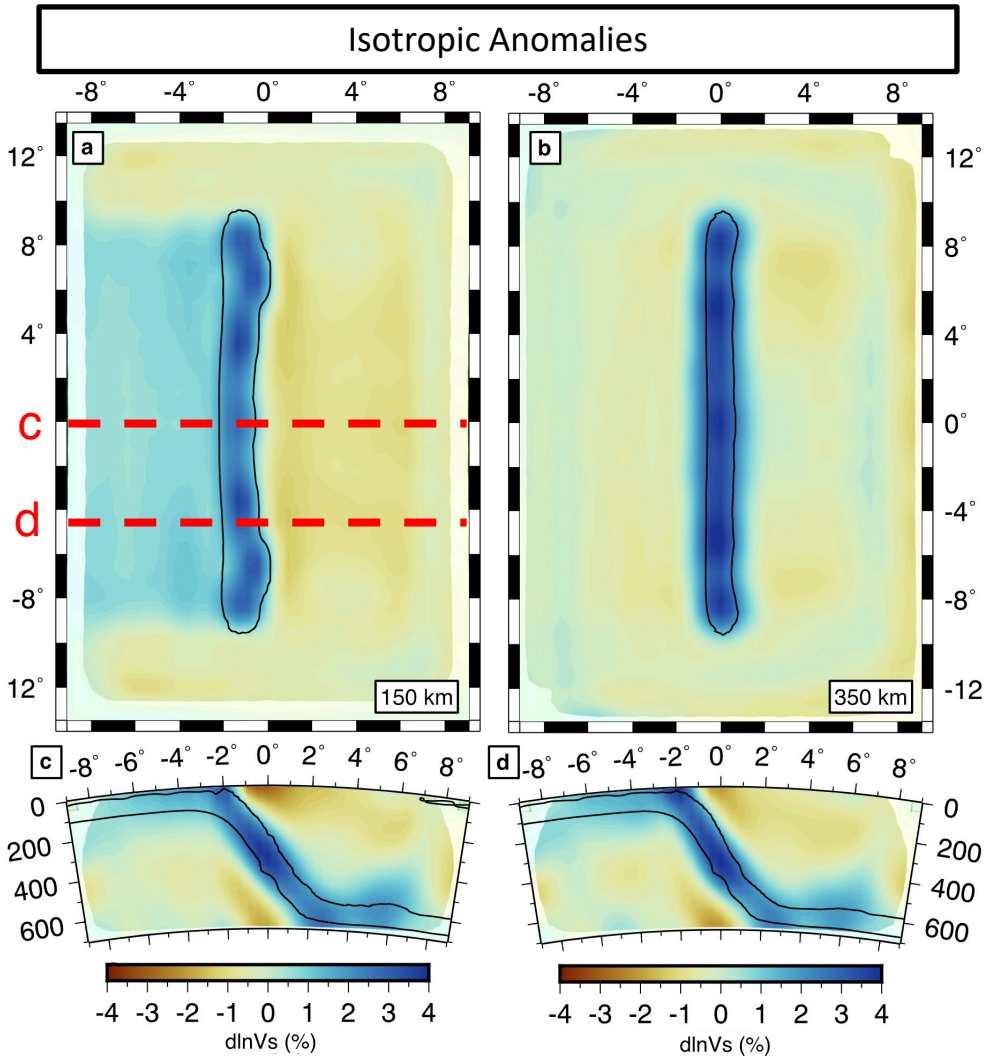
Isotropic Inversion of Isotropic Data



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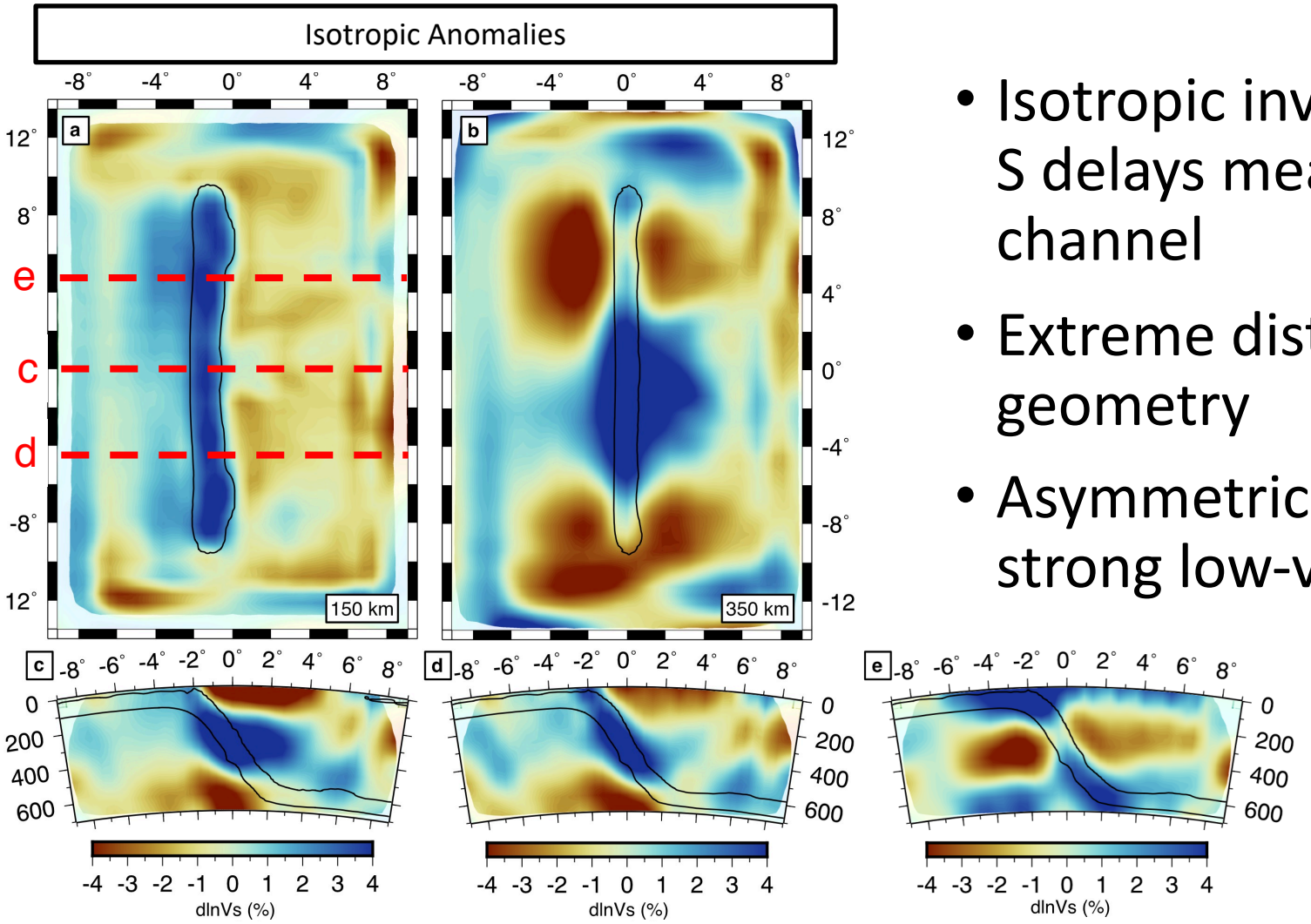
- Reference solution illustrating the ideal resolution of isotropic structure in absence of anisotropic heterogeneity
- Seismic waveforms modelled through purely isotropic model
- Inverted S delays measured on **transverse** channel via cross-correlation
- Basic slab structure is recovered

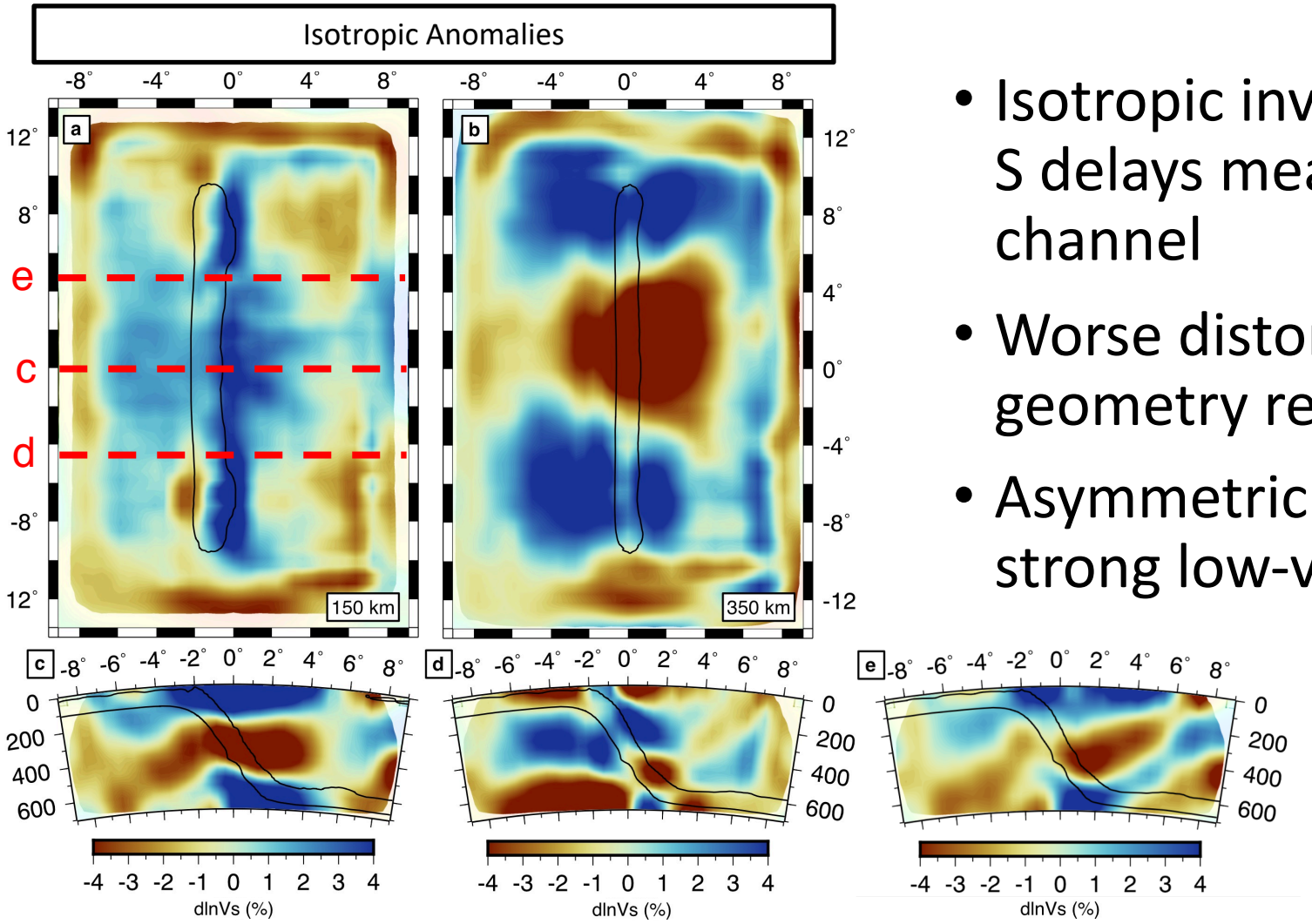
Isotropic Inversion of Anisotropic Data (Transverse)



Colormap Credit: Crameri, 2018

- Isotropic inversion of anisotropic S delays measured on **transverse** channel
- Extreme distortion of slab geometry
- Asymmetric slab structure and strong low-velocity zones

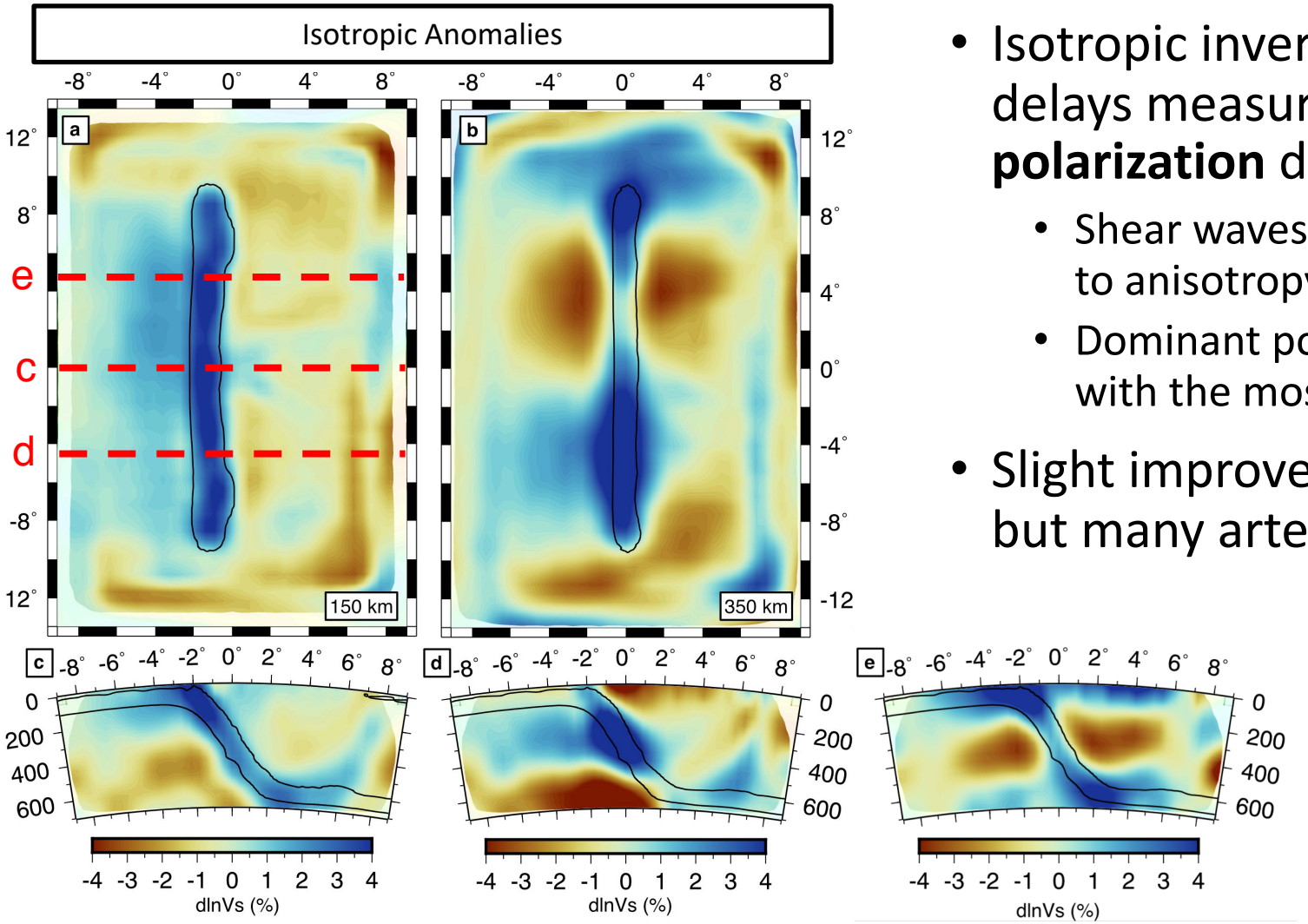
Isotropic Inversion of Anisotropic Data (Radial)



- Isotropic inversion of anisotropic S delays measured on **radial** channel
- Worse distortion of slab geometry relative to transverse
- Asymmetric slab structure and strong low-velocity zones

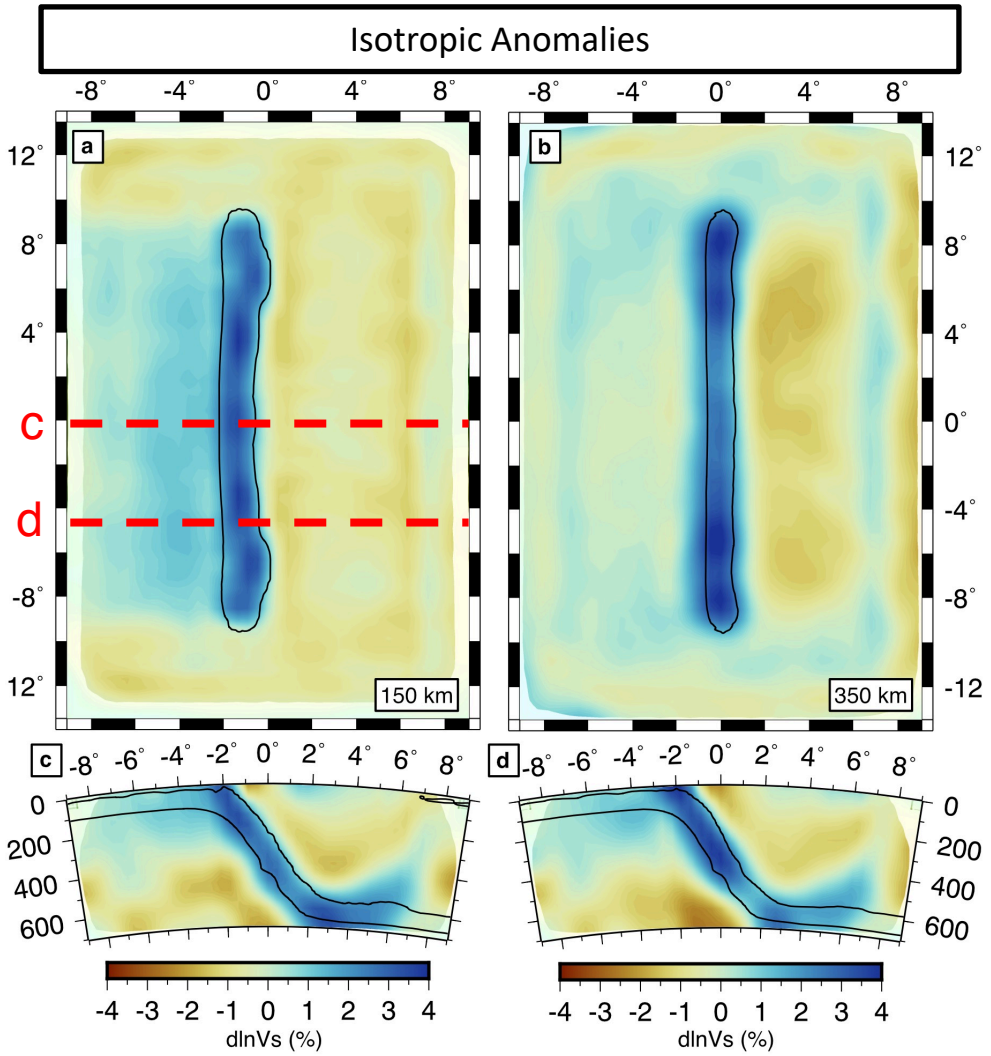
Colormap Credit: Crameri, 2018

Isotropic Inversion of Anisotropic Data (Polarization)



- Isotropic inversion of anisotropic S delays measured in the dominant **polarization** direction
  - Shear waves are elliptically polarized due to anisotropy
  - Dominant polarization direction is that with the most S-wave energy
- Slight improvement in slab recovery but many artefacts remain

Can We Forward Model Anisotropic S Delays? Yes!



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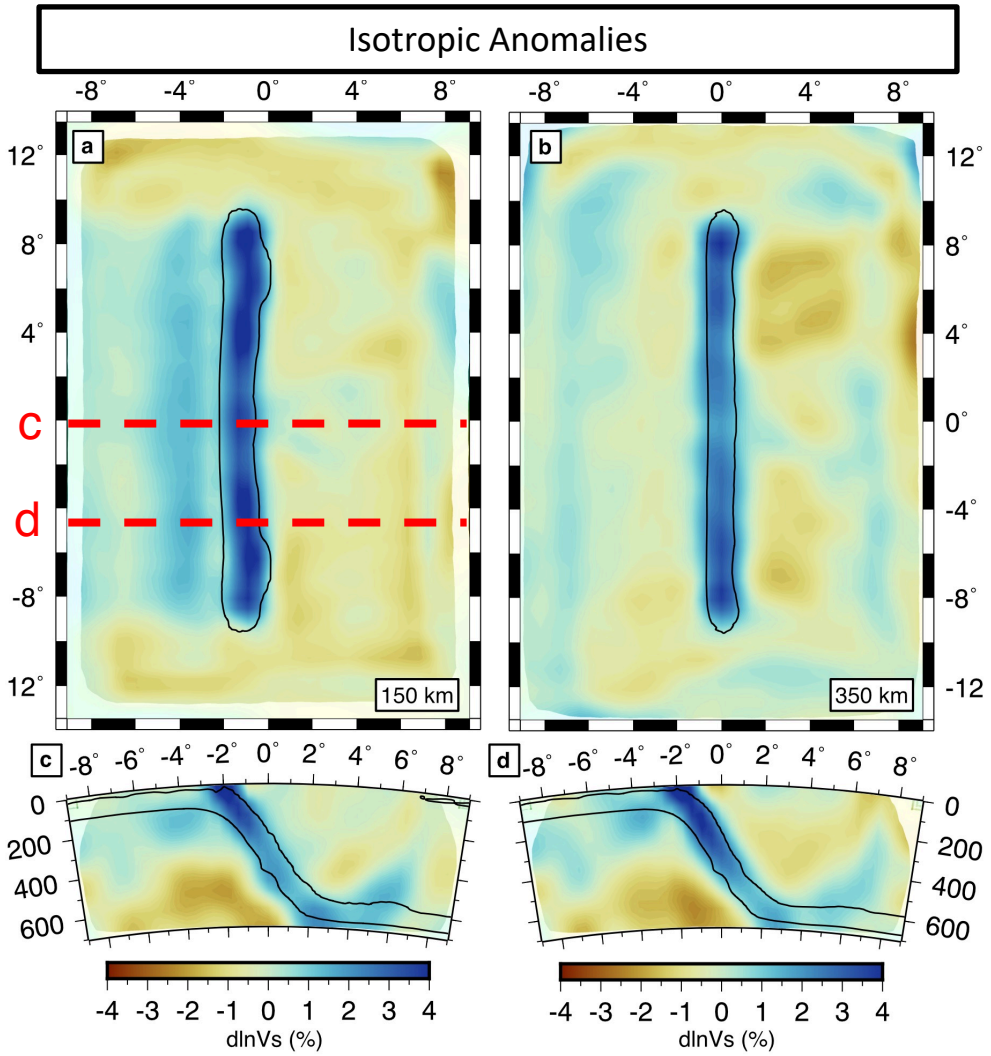
- When S delays are measured in the direction of dominant **polarization**, directional variations in travel-times can be approximated with sinusoidal functions of period *pi* and 2*pi*
  - The apparent S-wave velocity can be written as a function of the anisotropic symmetry axis, ray orientation, and dominant S-wave polarization direction
  - Details will be provided in upcoming publication
- Using this approximation and imposing the true anisotropic orientation and magnitude, the true slab geometry is well-recovered
- Our parameterization allows one to easily test the influence of arbitrarily oriented hexagonal anisotropy domains on S-wave travel-time tomography

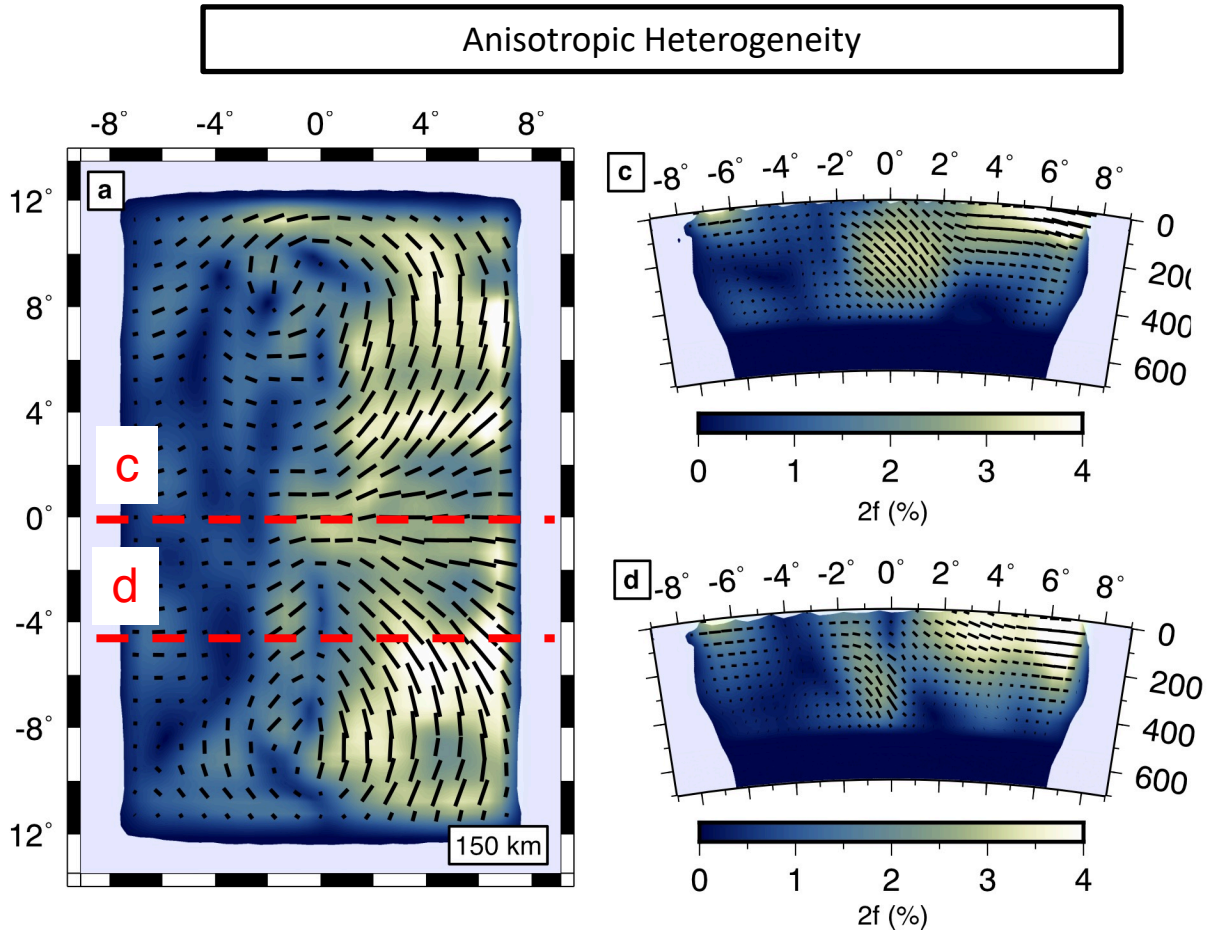
Can We Invert S Delays for Anisotropic Structure? Yes!



Colormap Credit: Crameri, 2018

- The sinusoidal approximation allows us to also invert for anisotropic structure using S delays in a manner similar to that proposed for P-waves (e.g. VanderBeek & Faccenda, GJI 2021)
- Isotropic slab structure is well-recovered when inverting S-delays for both isotropic and anisotropic parameters
- And…

Can We Invert S Delays for Anisotropic Structure? Yes!



- …We are also able to recover large-scale anisotropic features such as the toroidal flow pattern and steeply dipping fabrics associated with the descending slab

Colormap Credit: Crameri, 2018

Conclusions

- Unaccounted for anisotropic structure can significantly corrupt S-wave images of isotropic upper mantle velocities
- S-delays can be inverted for simplified anisotropic parameters (azimuth, dip, and magnitude) in a manner similar to P-waves (e.g. VanderBeek & Faccenda, GJI 2021)
- Modelling anisotropic structure is key to accurately recovering subduction zone shear velocity heterogeneity