Layered anisotropy beneath the Japan Sea and NE China from inversion of surface wave dispersion using rj-MCMC Algorithm

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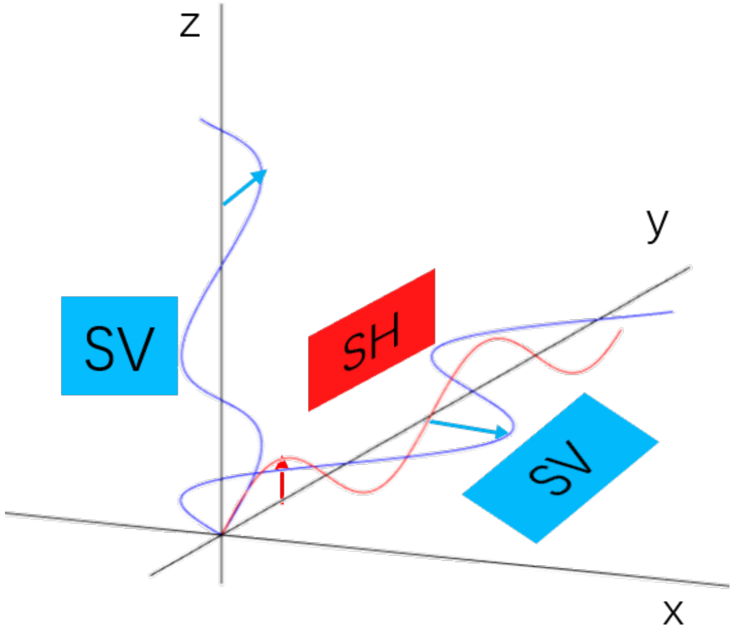
Part I : Anisotropy

- **Radial Anisotropy：**

Transversely isotropic, with 5 elastic constants： C、A、L、N、F

$$V_{PV} = \sqrt{C/\rho}\ , V_{PH} = \sqrt{A/\rho}\ , V_{SV} = \sqrt{L/\rho}\ , V_{SH} = \sqrt{N/\rho}, V_{PF} = \sqrt{F/\rho}$$



Isotropic parallel to the x-y plane

- **Azimuthally Anisotropy：**

Elastic constants (and corresponding velocities) vary with azimuth

Part I : Anisotropy

- **Classical representation of Rayleigh-wave and shear wave velocity azimuthal anisotropy**

  - Rayleigh-wave velocity

$$\delta c_R(\omega,\psi) \approx a_0(\omega) + a_c(\omega)\cos 2\psi + a_s(\omega)\sin 2\psi$$

$$\delta c_R(\omega,\psi) \approx \int_0^H [\frac{\partial c_R(\omega)}{\partial A}(\delta A + A_c\cos 2\psi + A_s\sin 2\psi) + \frac{\partial c_R(\omega)}{\partial L}(\delta L + L_c\cos 2\psi + L_s\sin 2\psi) + \frac{\partial c_R(\omega)}{\partial C}\delta C]dz$$

  - Shear-wave velocity

$$\hat{V}_{sv}(\psi) \approx \sqrt{\frac{L + L_c cos2\psi + L_s sin2\psi}{\rho}}$$

$$\approx V_{sv}\left(1 + \frac{L_c}{2L}cos2\psi + \frac{L_s}{2L}sin2\psi\right)$$

$$= V_{sv}(1 + A_{sv}cos2(\psi - \phi_F))$$

Smith & Dahlen (1973)
Montagner & Nataf (1986)
Yao(2015)

$$A_{sv} = 0.5\sqrt{G_c^2 + G_s^2} \qquad \phi_F = 0.5\tan^{-1}(G_s/G_c) \qquad (G_c = \frac{Lc}{L}, G_s = \frac{Ls}{L})$$

Inverse Problem

Rayleigh-wave
a_0, a_c, a_s

Shear-wave
V_{sv}, G_c, G_s

Part II: rj-MCMC algorithm

reversible jump Markov Chain Monte Carlo

Adjust dimension automatically

- **Dimension of the model space is variable:**
  - MCMC process is **reversible** itself
  - Transdimensional sampling, just like "**jumping**" between dimension-different model space

- **Acceptance Ratio α :**

current: $\boldsymbol{m}$ ➔ proposed: $\boldsymbol{m}'$ (i.e. $(\boldsymbol{m},\boldsymbol{m}')$or $(\boldsymbol{m}'|\boldsymbol{m})$)

$$\boxed{\alpha(\boldsymbol{m},\boldsymbol{m}') = \min\left\{1, \frac{p(\boldsymbol{m}')}{p(\boldsymbol{m})}\cdot\frac{p(\boldsymbol{d}_{obs}|\boldsymbol{m}')}{p(\boldsymbol{d}_{obs}|\boldsymbol{m})}\cdot\frac{q(\boldsymbol{m}|\boldsymbol{m}')}{q(\boldsymbol{m}'|\boldsymbol{m})}\cdot|\mathbf{J}|\right\}}$$

prior **proposal** **Jacobian determinant**

Likelihood Function:

$$p(\mathbf{d}_{obs}\mid\mathbf{m}) = \frac{1}{\sqrt{(2\pi)^n\,|\,\mathbf{C}_e\,|}}\times\exp\left\{\frac{-\Phi(\mathbf{m})}{2}\right\}.$$

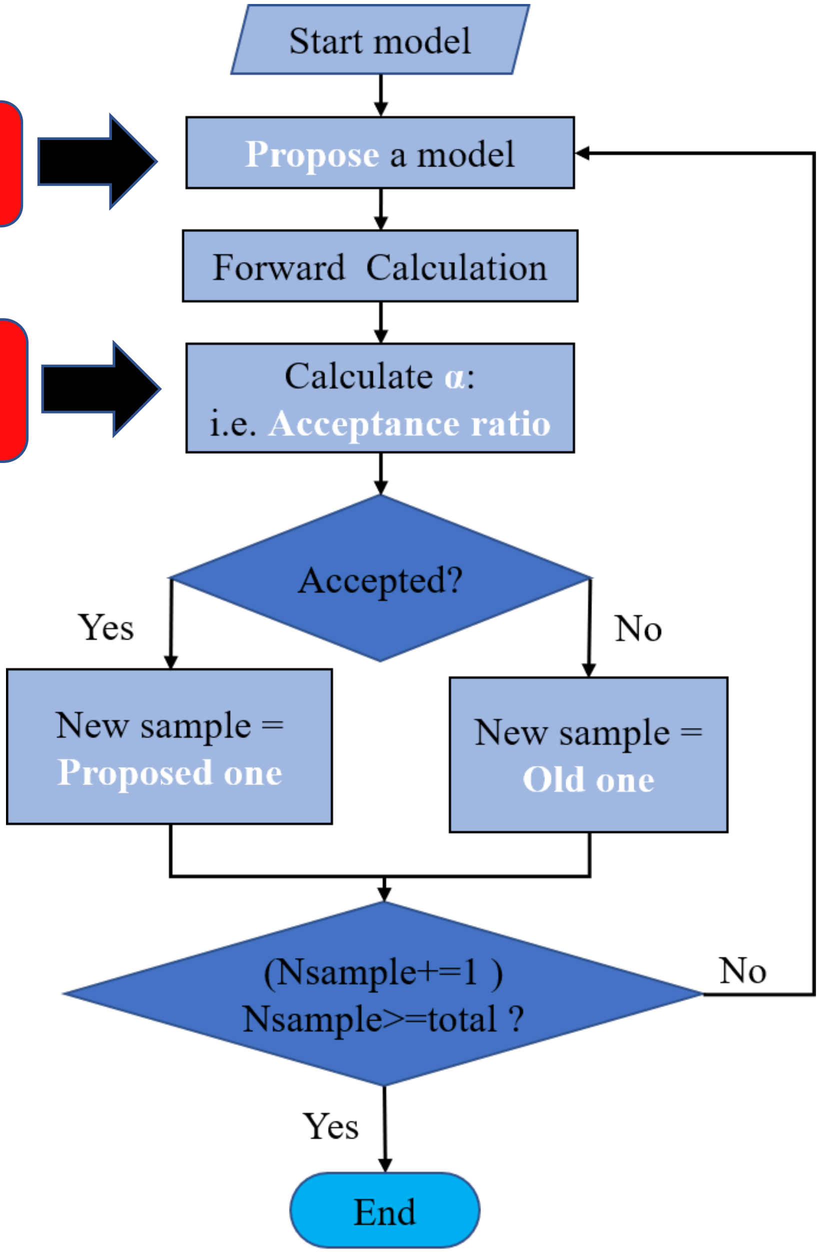
misfit: $\Phi(\mathbf{m}) = (g(\mathbf{m})-\mathbf{d}_{obs})^T\mathbf{C}_e^{-1}(g(\mathbf{m})-\mathbf{d}_{obs}).$

Data covariance matrix: $\mathbf{C_e} = \sigma_d^2\cdot\mathbf{I}$

Bodin et al.(2012)

Transdimensional proposal

Accept with probability of α



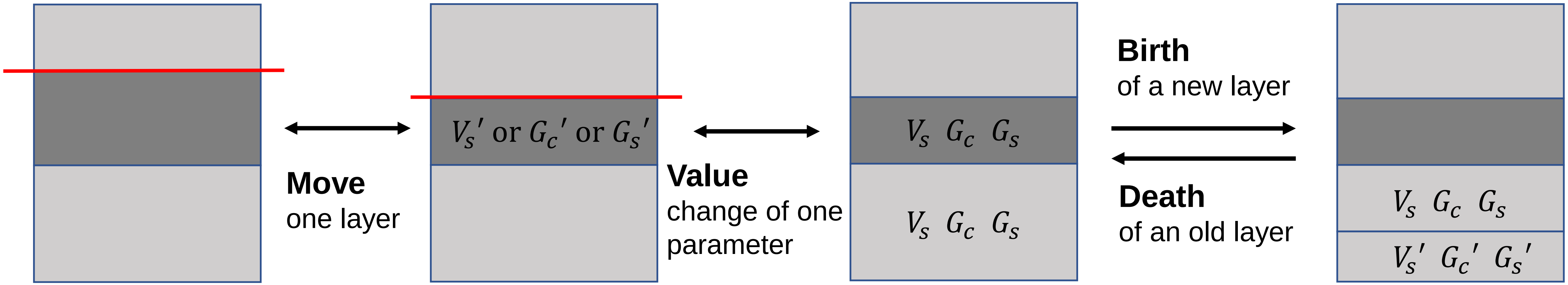
Part II: rj-MCMC algorithm

- Traditional inversion for Vs azimuthal anisotropy: **2 steps**

  (1) Inverse **isotropic** Vs model
  (2) Inverse **anisotropic** part based on Vs model of step (1)

- New method: **1 step**

  Inverse isotropic (Vs) and anisotropic part (Gc , Gs) simultaneously

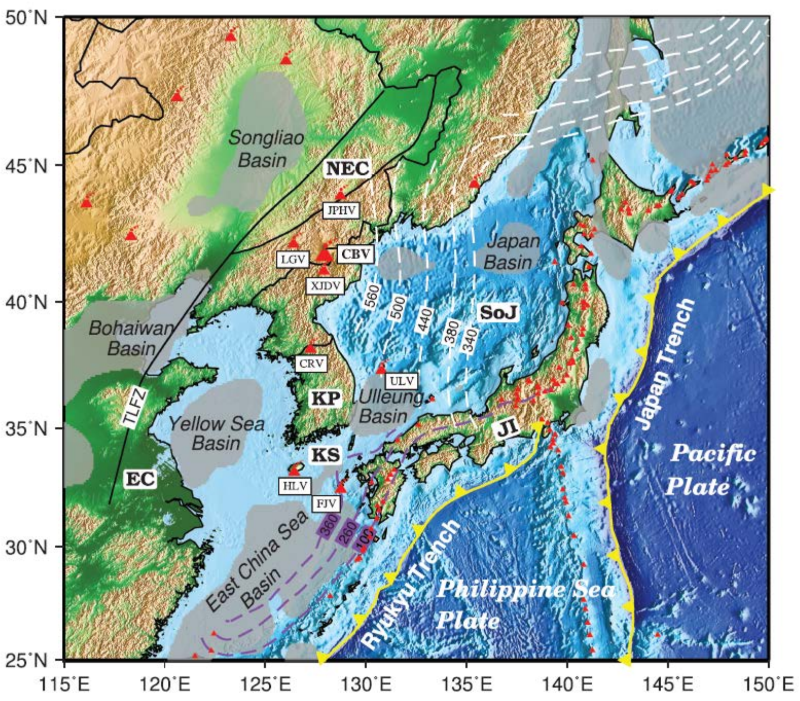


4 types of proposal processes in rj-MCMC algorithm

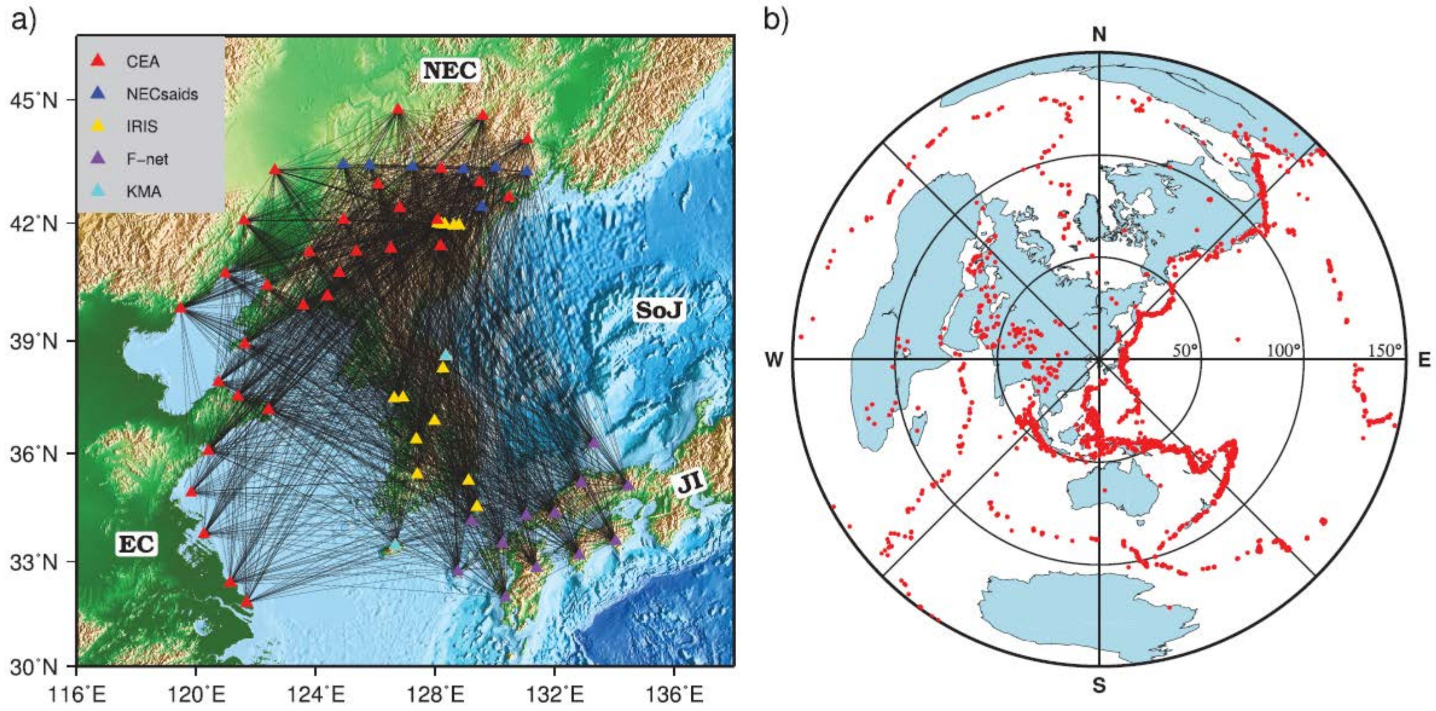
Pre-work

Our work is based on the pre-work of Fan et al.(2020)

- **Region:** NE Asia
- **Data:** seismic data from China, Japan, South Korea, and recently available data from North Korea



Tectonic background(Fan et al., 2020)



Distribution of stations, ray paths and selected earthquakes (Fan et al., 2020)

- ➢ CBV = Changbaishan volcano; JPHV = Jingpohu volcano; LGV = Longgang volcano; XJDV = Xianjingdao volcano; CRV = Chuga-Ryong volcano; ULV = Ulleung volcano; HLV = Halla volcano; FJV = Fukue-jima volcano.
- ➢ TLFZ =Tanlu fault zone
- ➢ NEC = northeast China; EC = East China; KP = Korean Peninsula; KS = Korea Strait; SoJ = Sea of Japan; JI = Japanese Island.

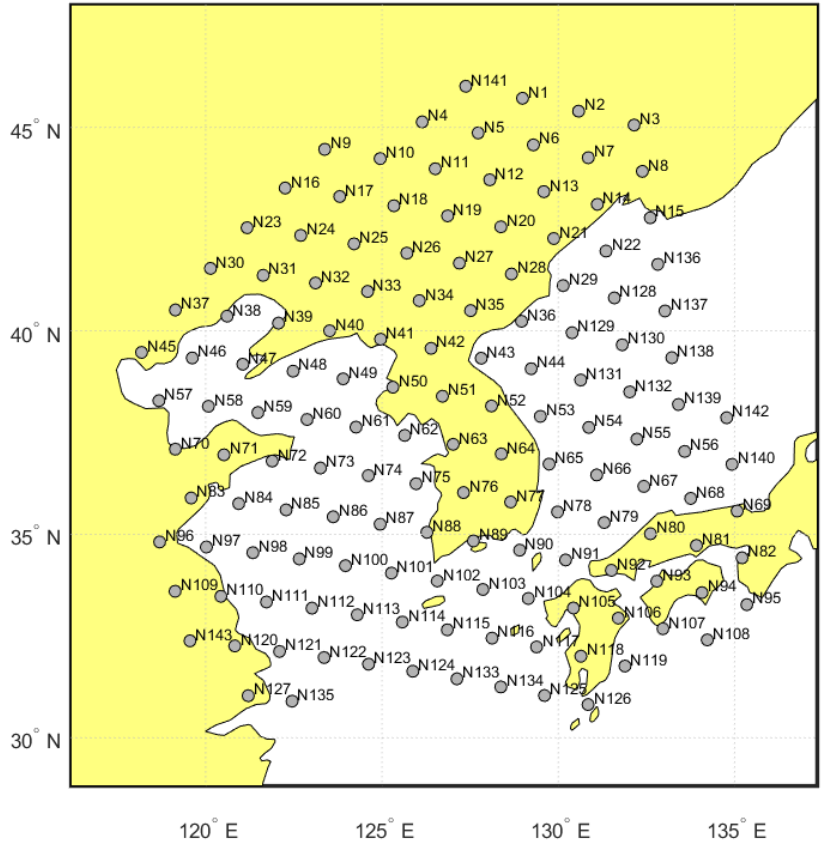
Pre-work

- **Results:** a high-resolution azimuthally anisotropic Rayleigh-wave velocity model

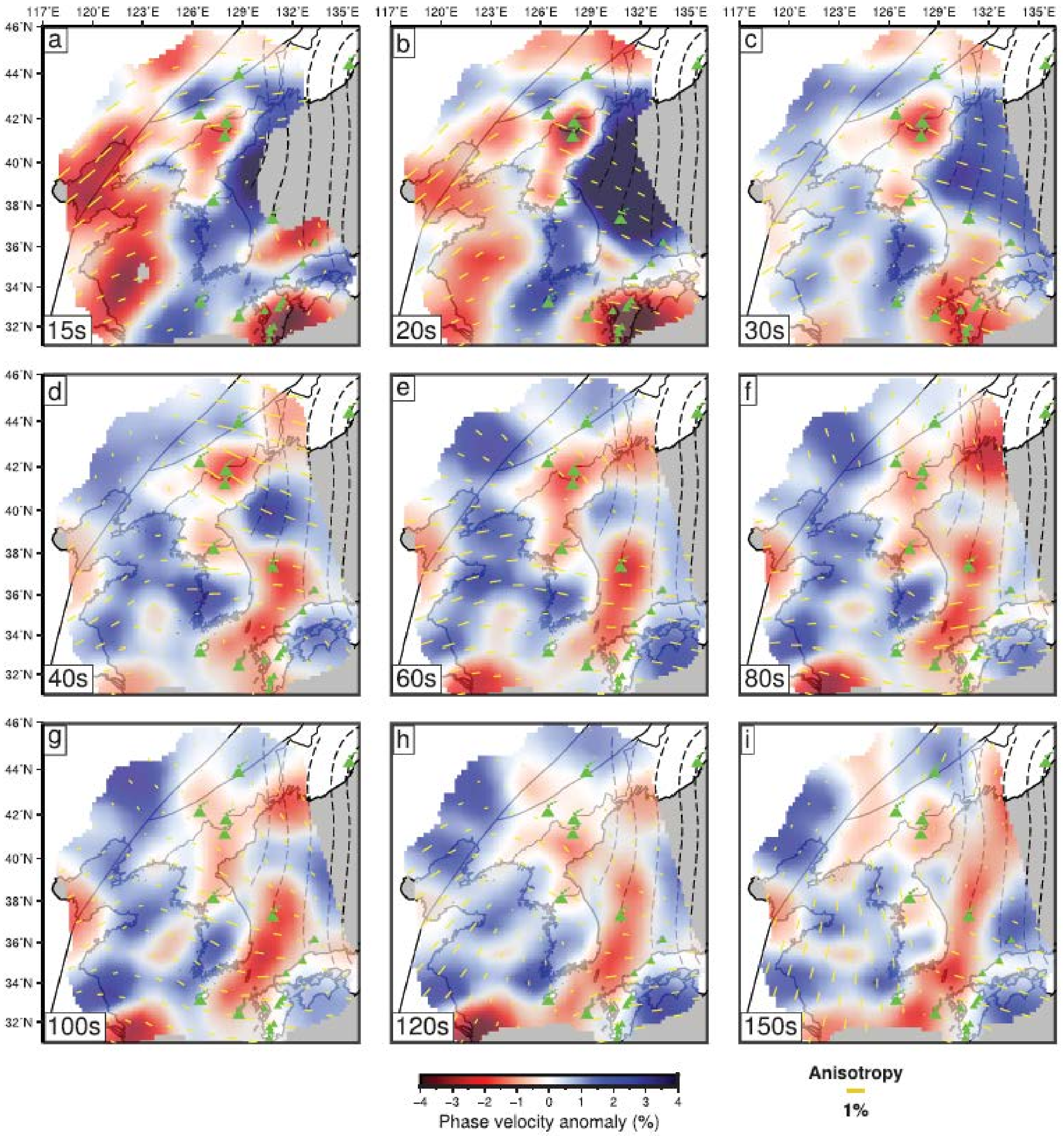
- **Our data:**

143 knots , periods of 15~150s Rayleigh wave:

- ➢ Isotropic wave velocity
- ➢ Azimuthally anisotropic coefficients



Distribution of 143 knots (i.e. the yellow bars of the maps).



Azimuthally anisotropic Rayleigh-wave phase velocity maps (Fan et al., 2020)

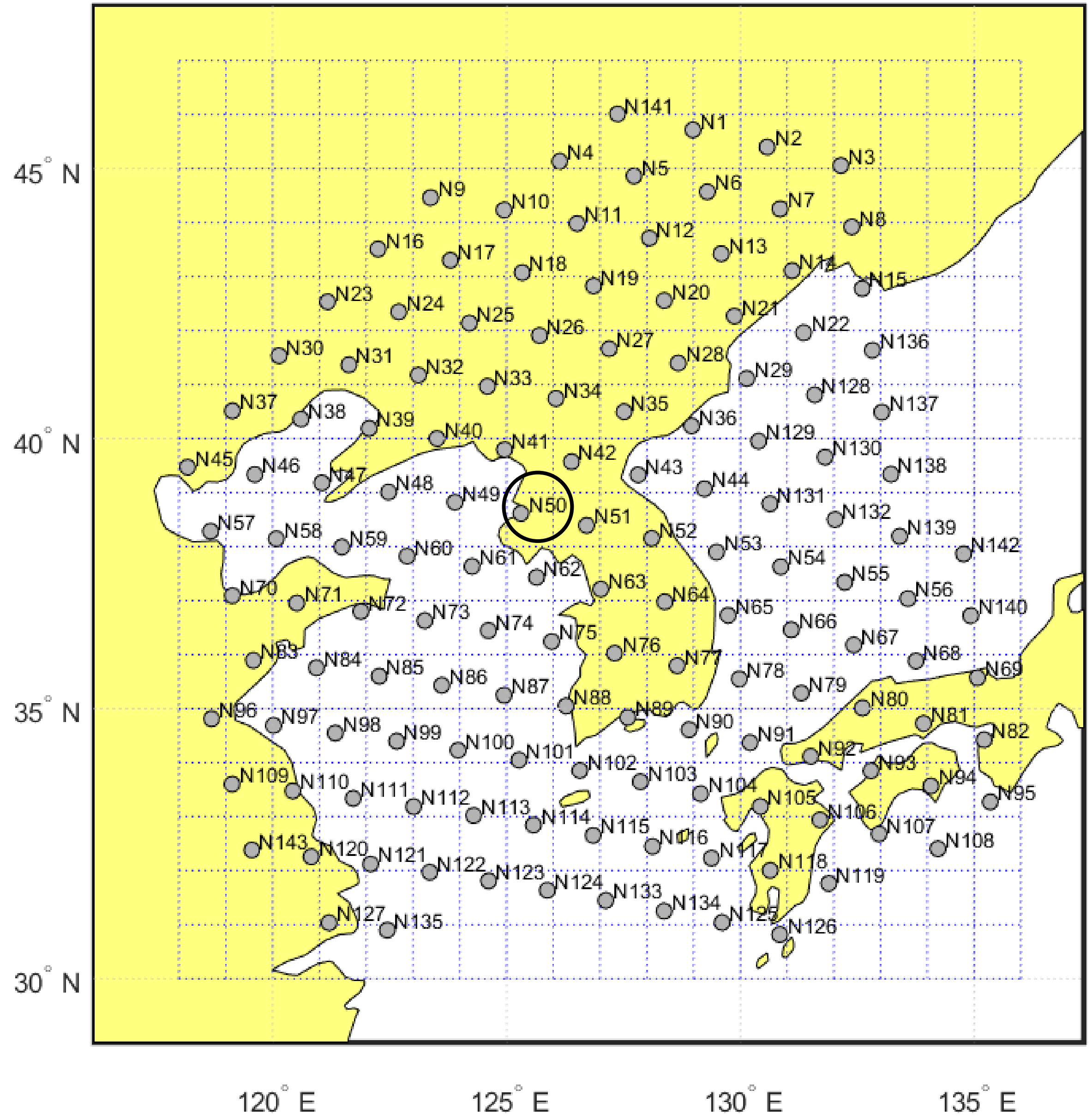
Results

1. Single Knot

- **prior distribution (refer to crust1.0 model)**
  - **Water/sedimentary** layers: crust1.0
  - **Moho** : crust1.0±5km
  - **Gc、Gs** : -0.1%~0.1%
  - **Vs** :
    Layer 1: 3.3~4.0km/s (Above Moho)
    Layer 2: 3.5~4.7km/s (For Moho)
    Layer 3: 4.0~5.0km/s (Moho~<300km)
    Layer 4: 4.3~5.0km/s (300~400km)

- **Take N50 for example**

  Located in the center of the region with high ray density



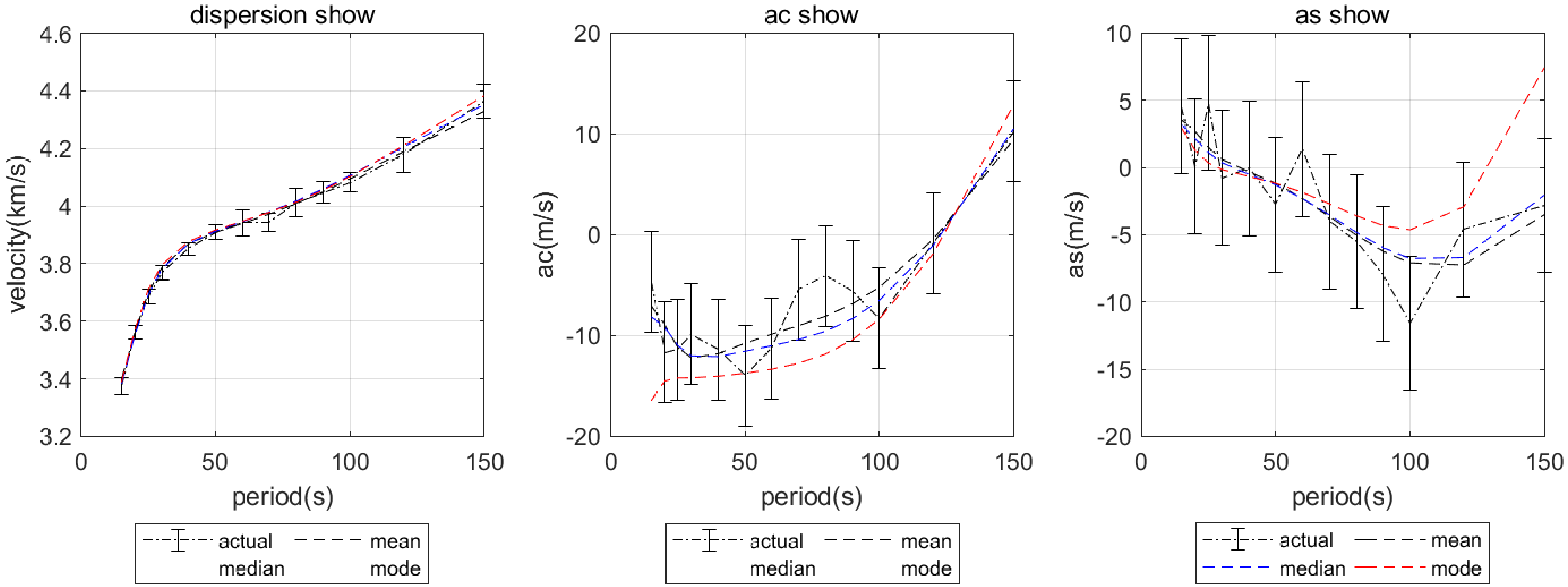
Distribution of 143 knots, with grids of crust1.0 model in this region

Results

1. Single Knot

Take N50 for example

- **Data fit**
  - **Good fit** for the **mean** and **median** solutions
  - **Relatively Bad fit** for the **mode** solution

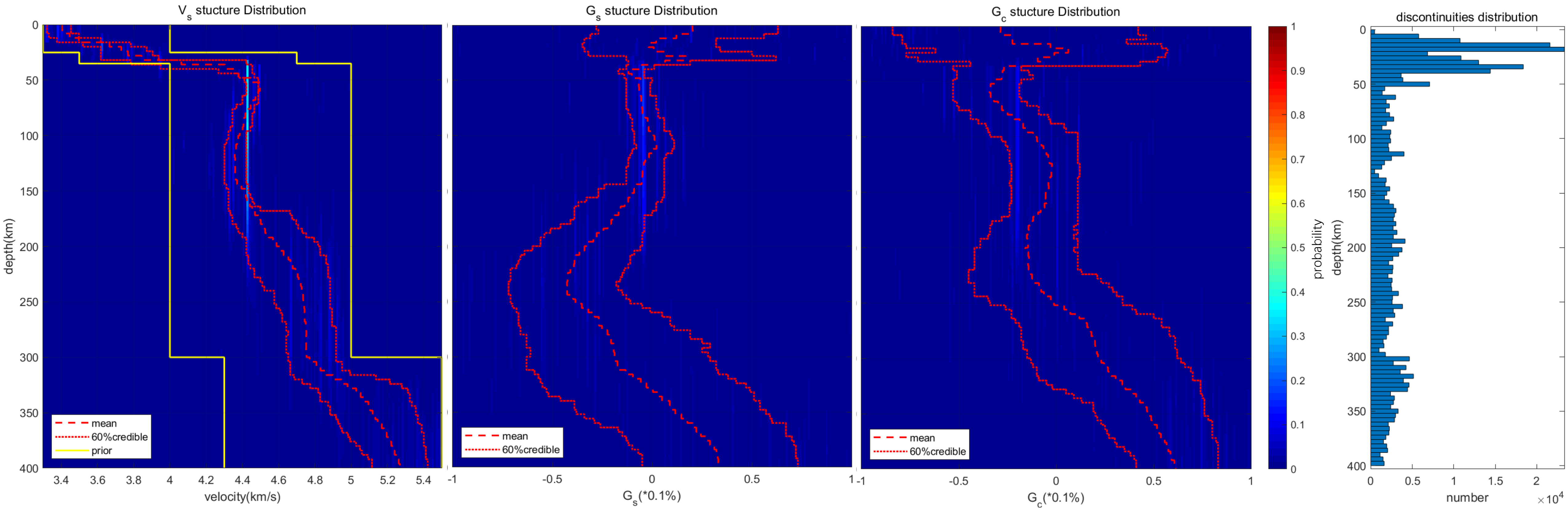


Results

1. Single Knot

Take N50 for example

- **2-D distribution for parameters**
  - **3 parameters distribution:** concentrate more obviously shallower than 200~250km
  - **Discontinuities distribution:** peaks are obvious in the shallow part but not in the deep part



Results

1. Single Knot

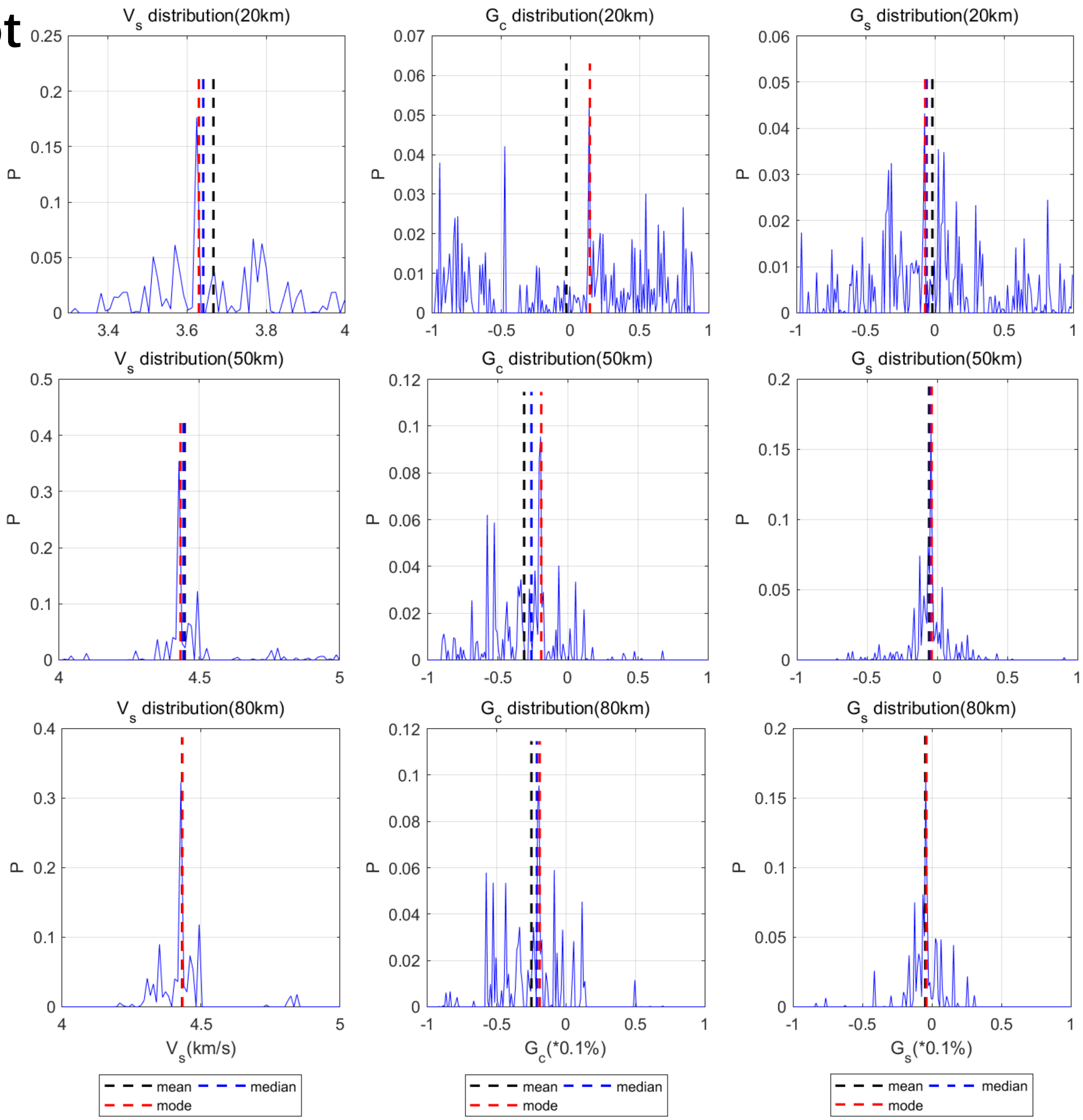
Take N50 for example

- **Distribution on profiles**

  Distribution on the profile of 20, 50, 80km

  - Good distribution for 50~80km (Uppermost mantle). Not good distribution for 20km (crust).

  - Relatively not good distribution for Gc



Results

1. Single Knot

Take N50 for example

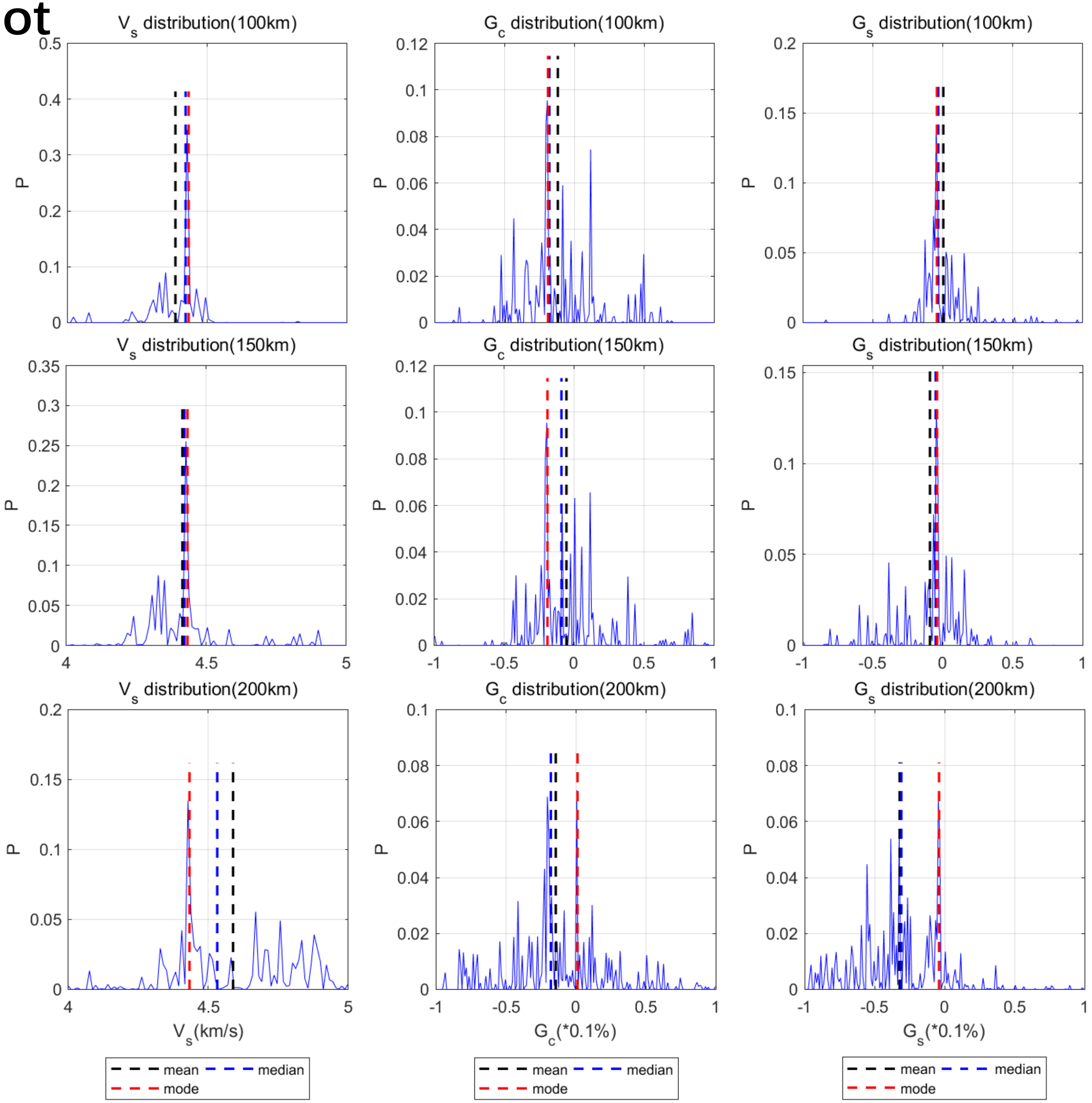
- **Distribution on profiles**

Distribution on the profile of 100, 150, 200km

➢ Good distribution for 100~150km (middle Upper mantle). Not good distribution for 200km (including below ~200km) .

➢ Relatively not good distribution for Gc

- **May need to constrain Vs well first**
- **Need wider period range**



1. Single Knot

Take N50 for example

- **Sampling results: number of layers**
  - ➢ **Tend to choose more layers:**

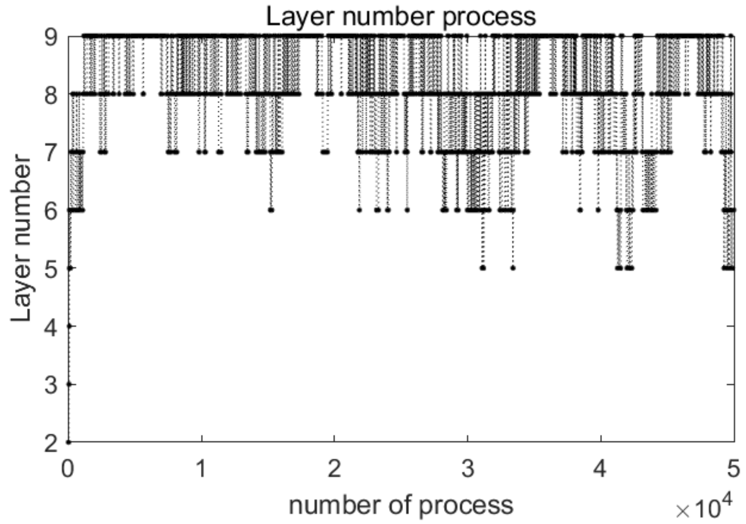
Do not adjust dimension automatically

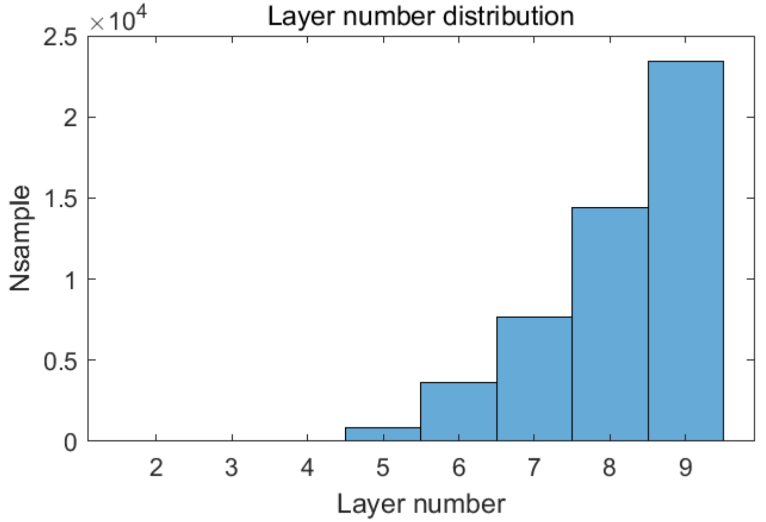
  - ➢ **Number of peaks in discontinuities distribution do not match the layer number with high probability:**

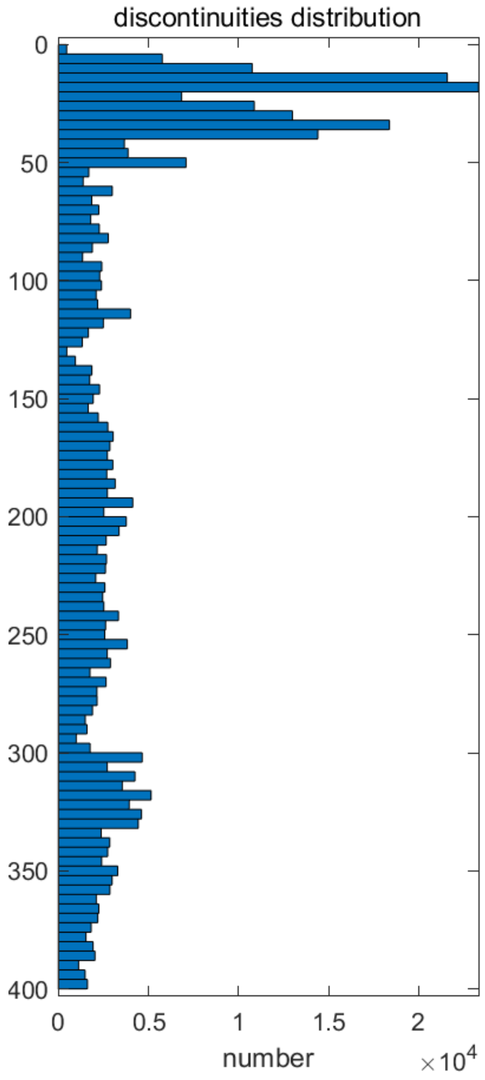
Some meaningless layer was preserved in sampling process

Reason ?
Surface wave:
integral property of the underground structure

- **Need more types of data (not just surface wave) to constrain the different properties, like discontinues**



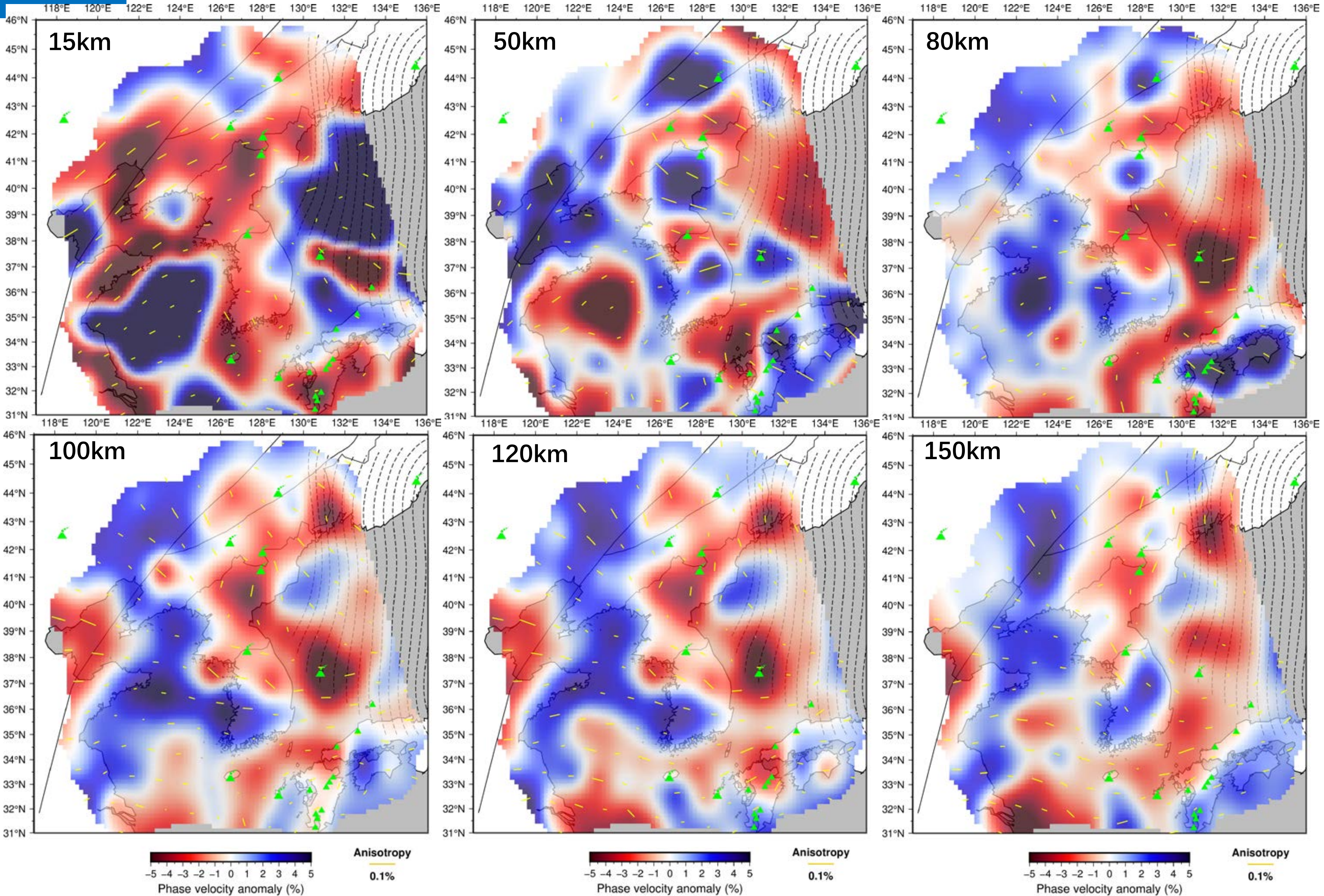




Results

2. The Whole Region

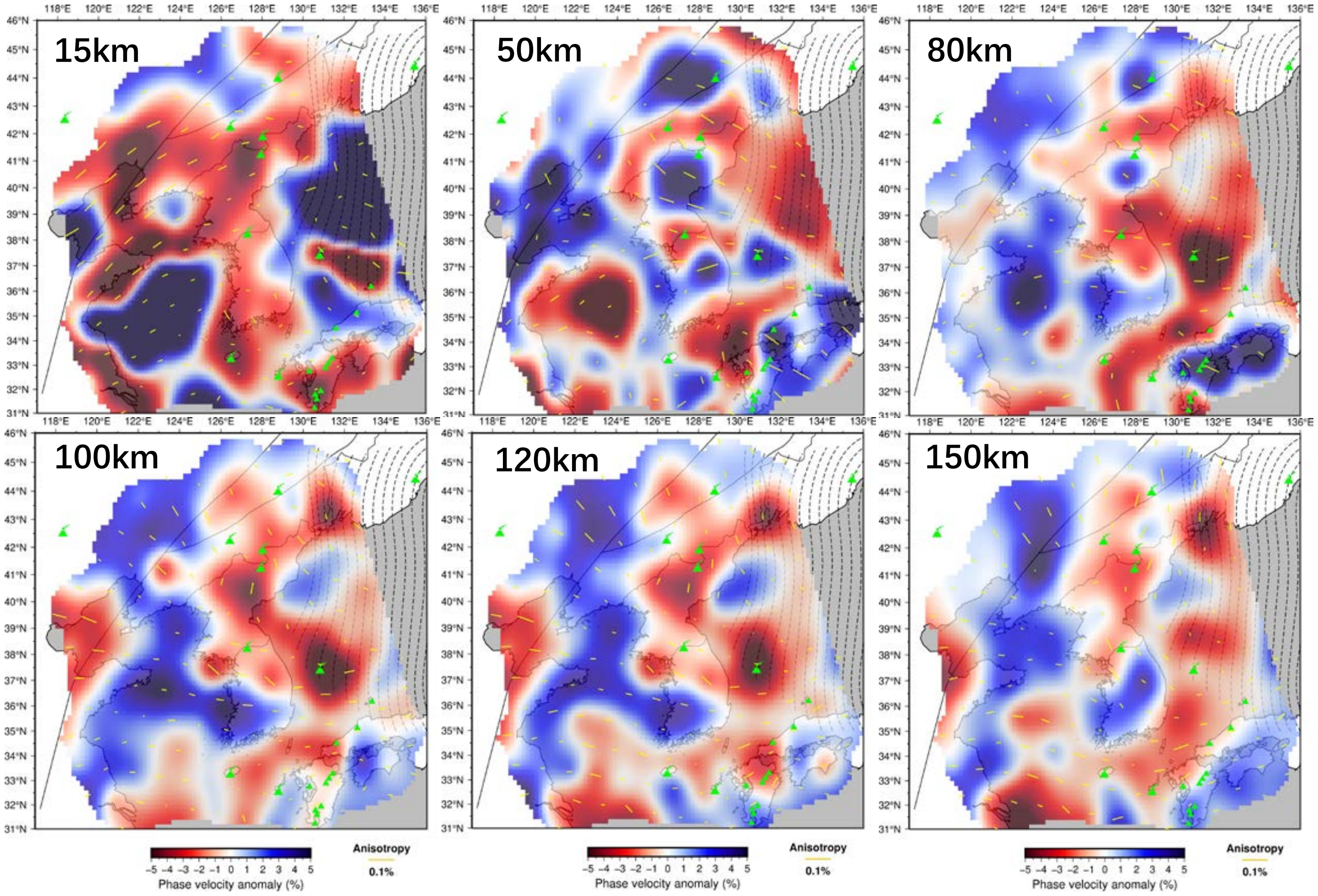
Choose the mean solution



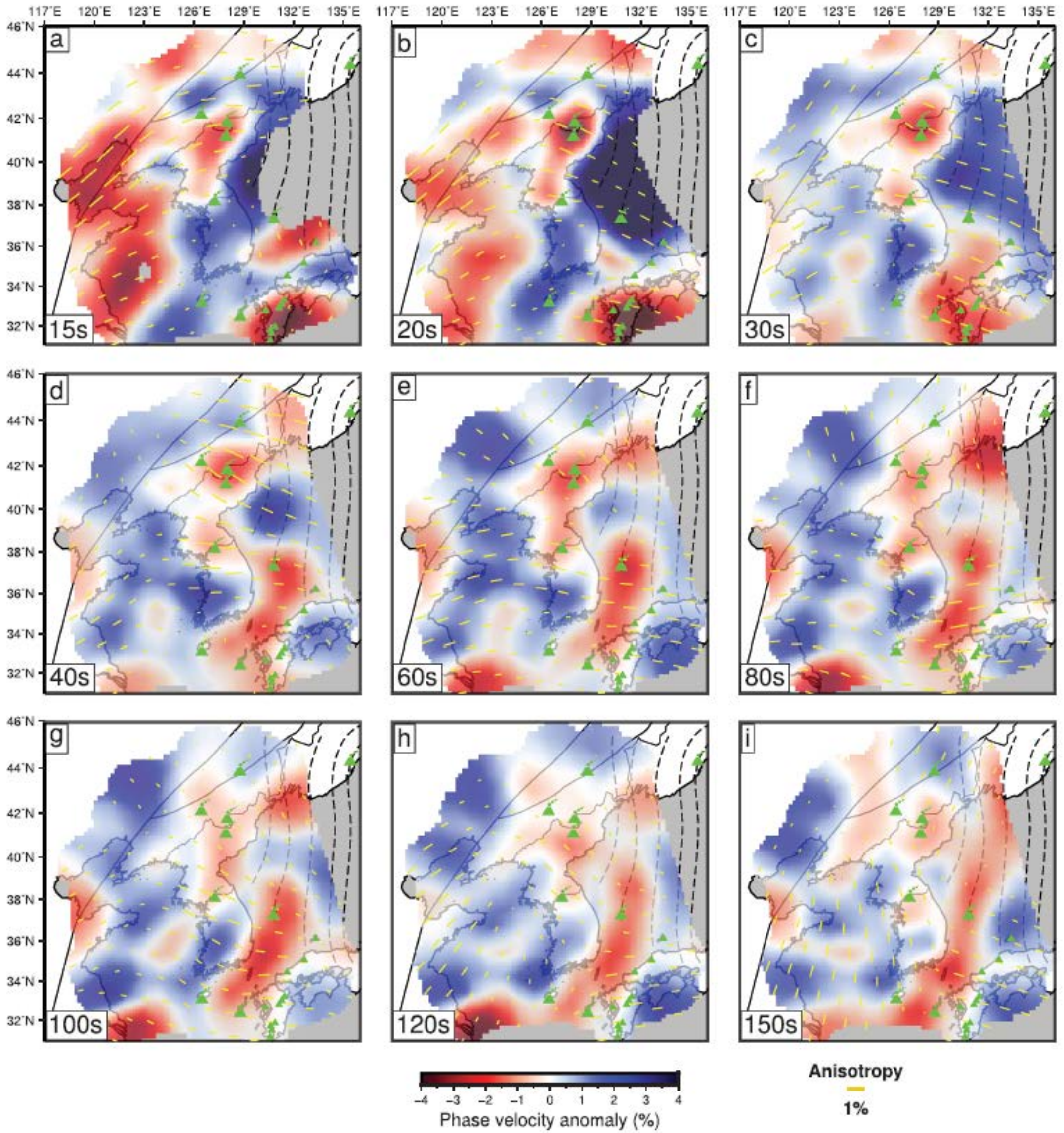
Azimuthally anisotropic
Shear-wave phase velocity
maps of this work

2. The Whole Region

- **Comparation between shear wave and Rayleigh-wave results**



Azimuthally anisotropic Shear-wave phase velocity maps of this work

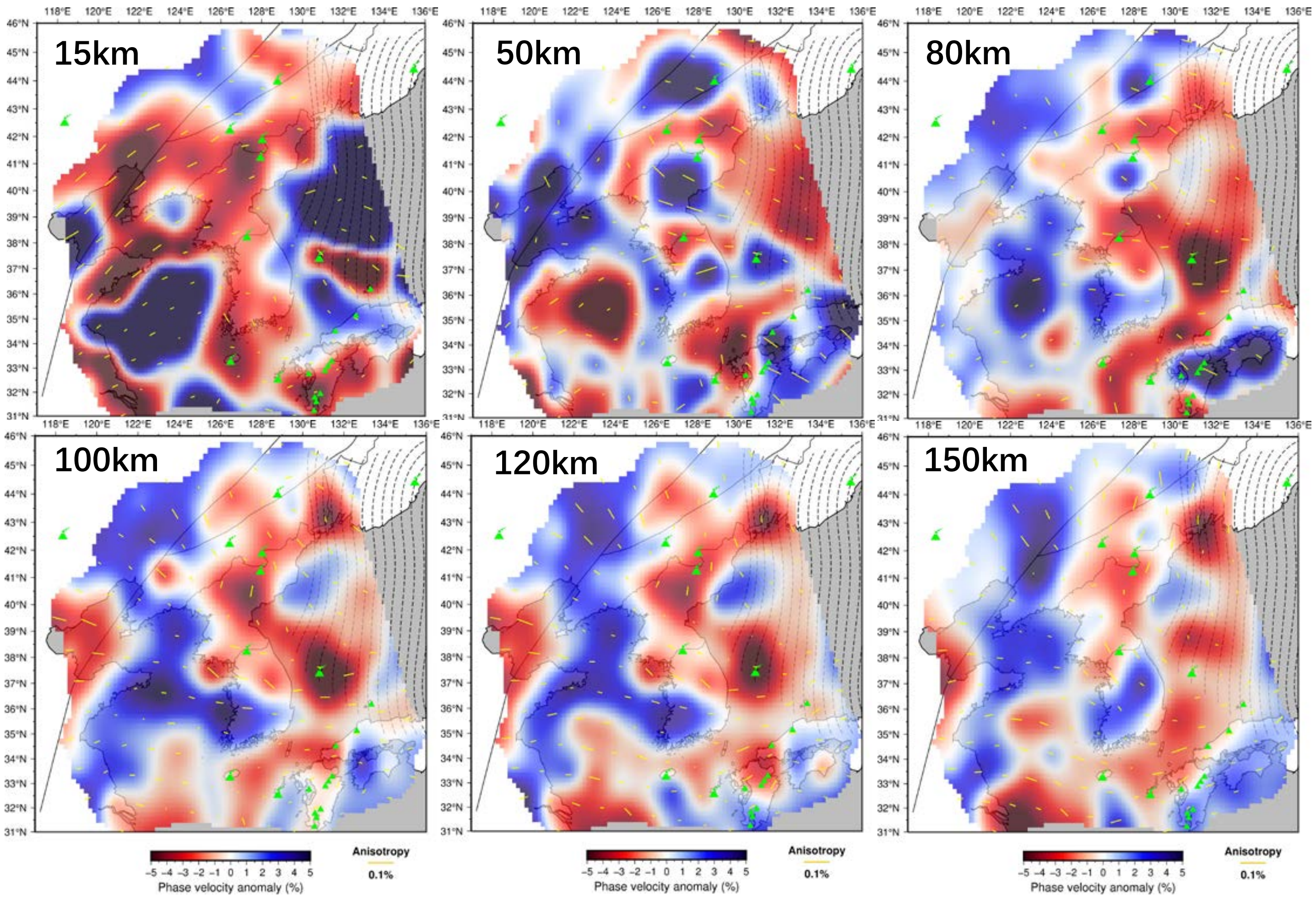


Azimuthally anisotropic Rayleigh-wave phase velocity maps (Fan et al., 2020)

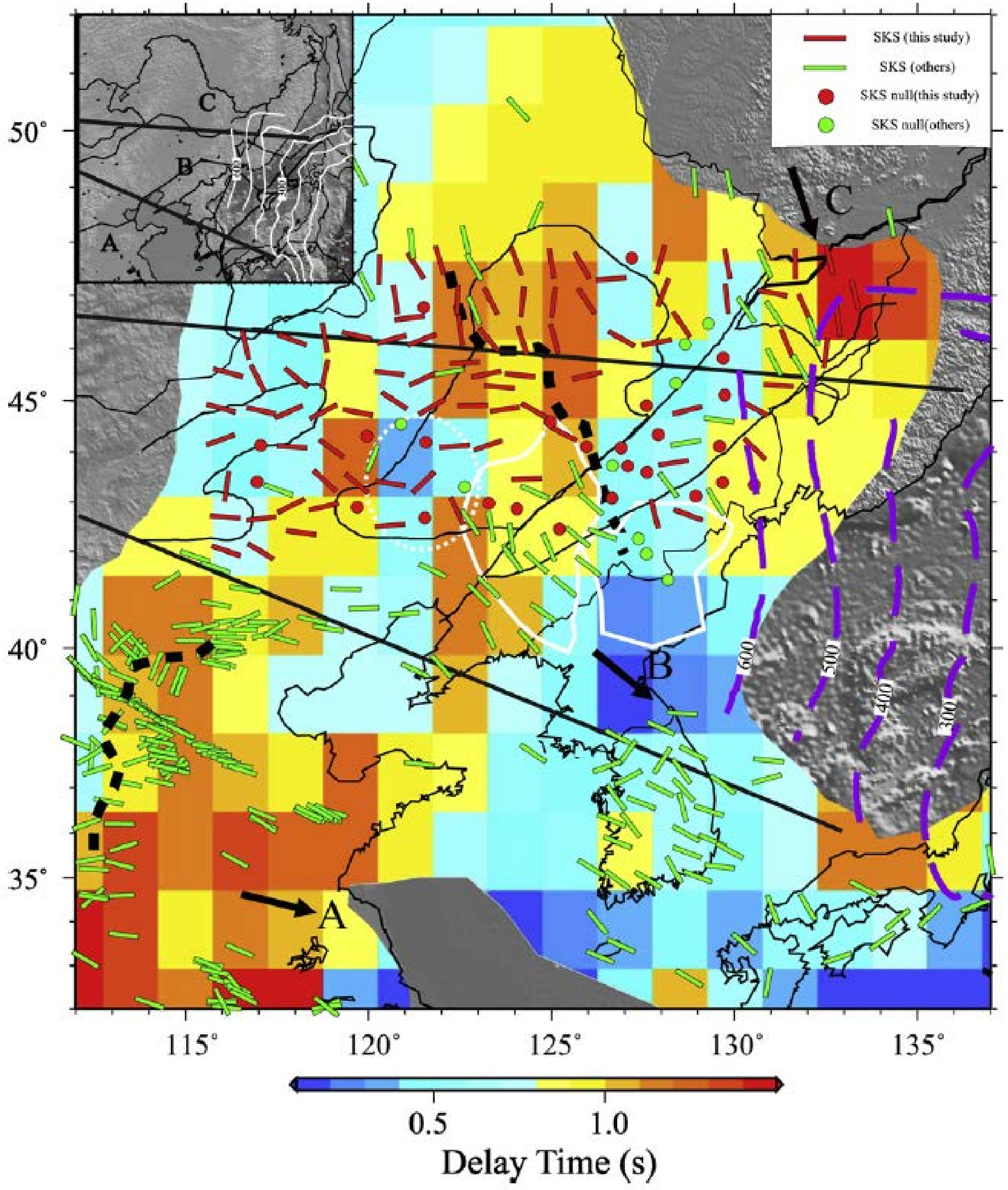
Results

2. The Whole Region

- **Comparation between our work and the results from SKS splitting method**



Azimuthally anisotropic Shear-wave phase velocity maps of this work



SKS splitting results (Shilin Li et al., 2017)

2. The Whole Region

- **Crust**:
  - East of China: NE-SW direction, similar to the strike direction of the Tanlu Fault Zone.
- **Upper Mantle**:
  - The anisotropy perpendicular to the subduction zone in is observed in the back-arc region of the Western Pacific Ocean in the Japan Sea and the Korean Peninsula.
- **Middle Upper Mantle**:
  - The near ES-WN direction of azimuthal anisotropy in the middle upper mantle East of China is consistent with the result from shear wave splitting method.
- **Problem**:
  - The amplitudes of the anisotropy are very small, which can not be explained well
  - Some results of the uppermost mantle are irregular and can not be explained well

Discussion and Conclusion

About rj-MCMC algorithm

- **Good distribution** can be obtained for the depths **reflected well in the period range**.
- The distributions of anisotropic parameters are not as good as that of the isotropic velocity, which may reflect **the inefficient of simultaneous inversion of three parameters**.
- The advantage of rj-MCMC algorithm, i.e. adjusting dimension automatically, is not shown in this work. This may be because of **the lack of different types of data**, e.g. the receiver function data or shear wave splitting data which is sensitive to different properties.

About Vs and anisotropy results

- **Isotropy**: The isotropic Vs structure anomaly is partially consistent with the result of Rayleigh wave, like the low velocity regions of the upper mantle beneath the volcanos. But it is not good enough.
- **Anisotropy**:
  - ➢ The azimuth of S wave shows partial consistency with that of Rayleigh wave, especially in the east/northeast China, but may be not good enough near the Japan Sea. The amplitudes of anisotropy are generally small, which can not be explained well.
  - ➢ The anisotropy results of this work shows consistency with the SKS splitting results, especially in the east/northeast China and near the trench southeast of Japan.
- *The results need to be further explained, and that will be supplemented with more results later ……*

Discussion and Conclusion

Future work

- Complete the inversion of anisotropy in this work
- Do the joint inversion with other types of data using the rj-MCMC algorithm. **In the near future, we plan to add the SKS splitting data.**
- **Improve the algorithm** and compare it with some other algorithms.

This work is still in progress and a lot of work remains to be done.

Hopefully I appreciate any comment on this study or any ideas you want to share.

More detailed information about the comments or ideas could be sent by e-mail (in the first page or the EGU website) to me if it is convenient for you.

Many thanks for reading!

Reference

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