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Seismic imaging of the South China Block and the South China Sea

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2017-07-23, Beijing

大地测量与地球动力学国家重点实验室
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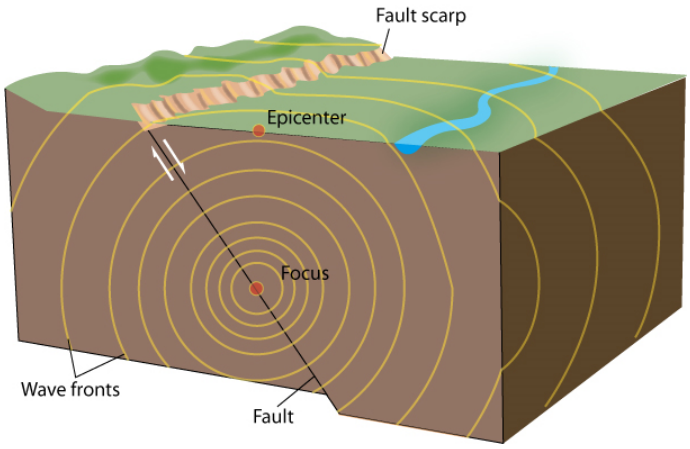
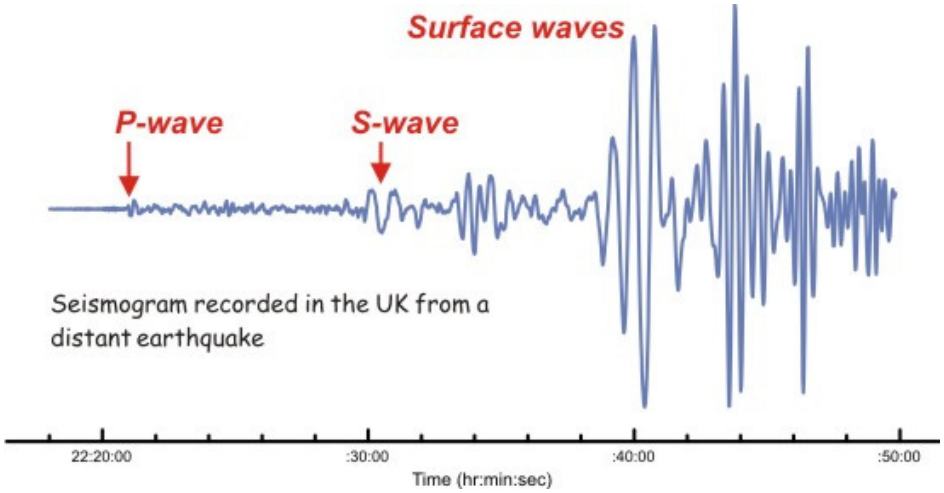
Outline

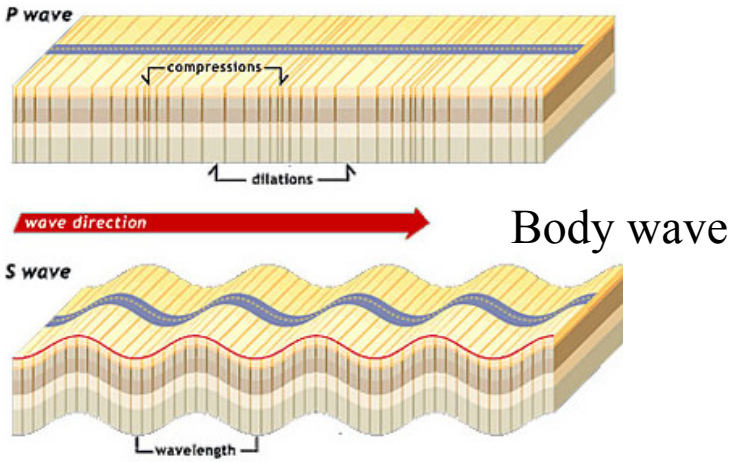
- Background
- Seismic imaging of South China Blcok
- Seismic imaging of South China Sea
- Future works on seismic imaging methods
- Conclusions

Background

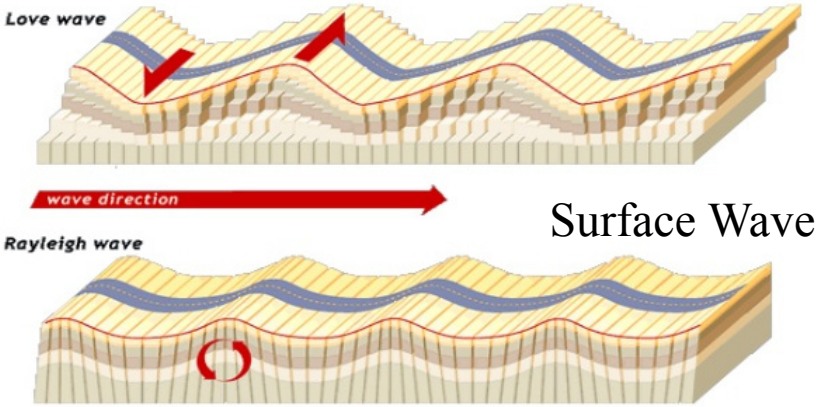
Seismic imaging is one of the most effective method to obtain the 3-D velocity structures of the Earth's interior.







Body wave

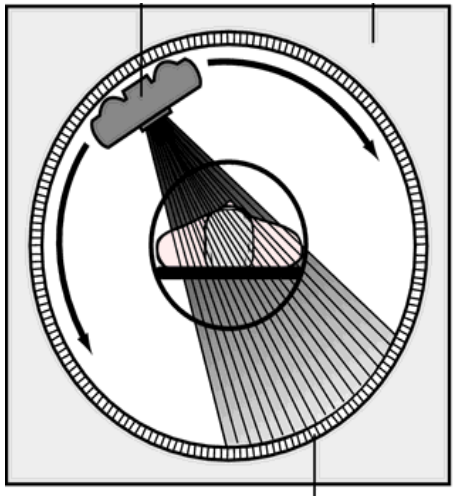


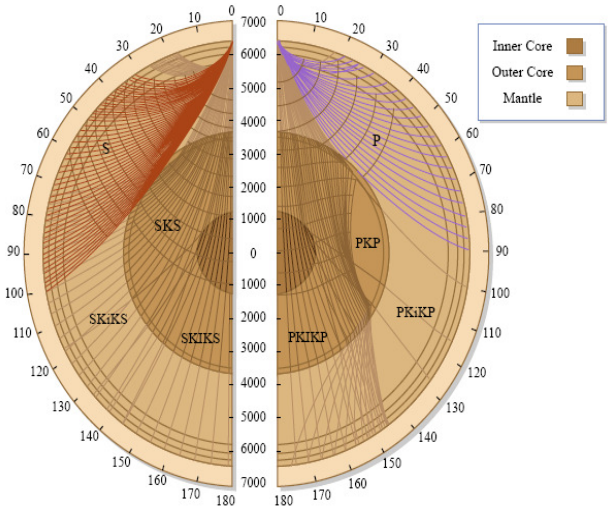
Surface Wave

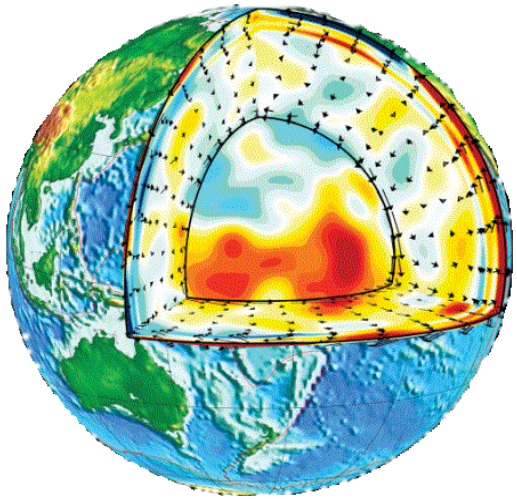
$$\delta t_{ij}^{\mathrm{p}} = t_{ij}^{\mathrm{obs}} - t_{ij}^{\mathrm{cal}} = \sum \frac{\partial t}{\partial S_k^{\mathrm{p}}} \Delta S_k^{\mathrm{p}} + \sum_{l=1}^{4} \frac{\partial t}{\partial q_l^i} \Delta q_l^i$$

$$\delta t_{ij}^{\mathrm{s}} = t_{ij}^{\mathrm{obs}} - t_{ij}^{\mathrm{cal}} = \sum \frac{\partial t}{\partial S_k^{\mathrm{s}}} \Delta S_k^{\mathrm{s}} + \sum_{l=1}^{4} \frac{\partial t}{\partial q_l^i} \Delta q_l^i$$

$$\sum \frac{\partial t}{\partial S_k^s} \Delta S_k^{\mathrm{s}} = \sum \frac{\partial t}{\partial S_k^{\mathrm{s}}} \Delta (r_k S_k^{\mathrm{p}}) = \sum \frac{\partial t}{\partial S_k^s} (S_k^{\mathrm{p}} \Delta r_k + r_k \Delta S_k^{\mathrm{p}})$$







Seismic Velocity

(Vp, Vs, Possion's ratio)

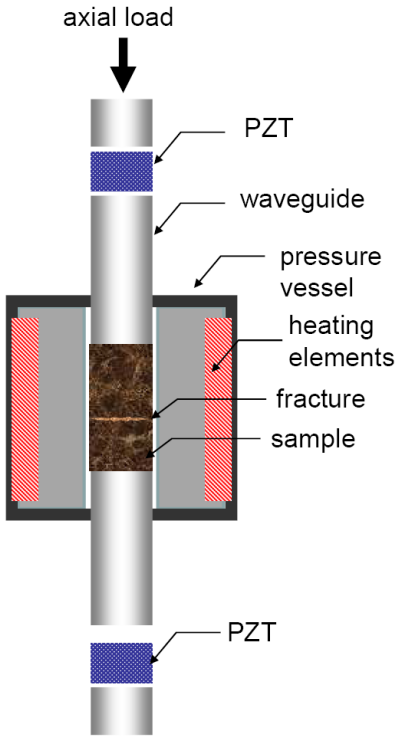
$$\sigma = \frac{1}{2}(1-[(v_p / v_s)^2 - 1]^{-1})$$

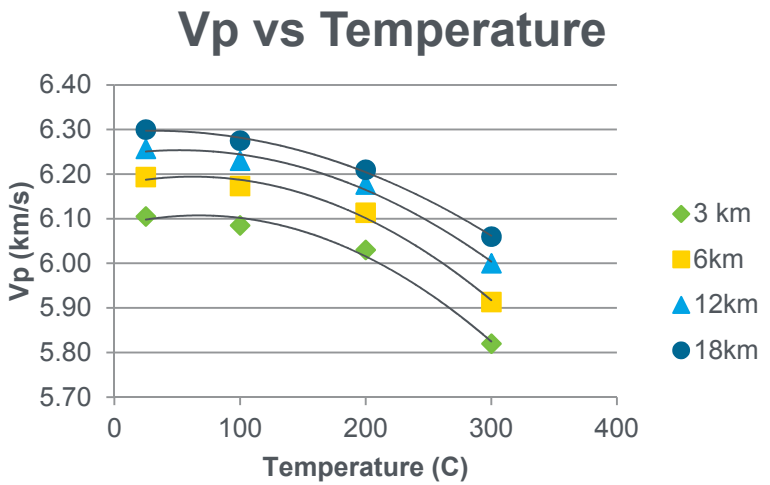
Density

Composition

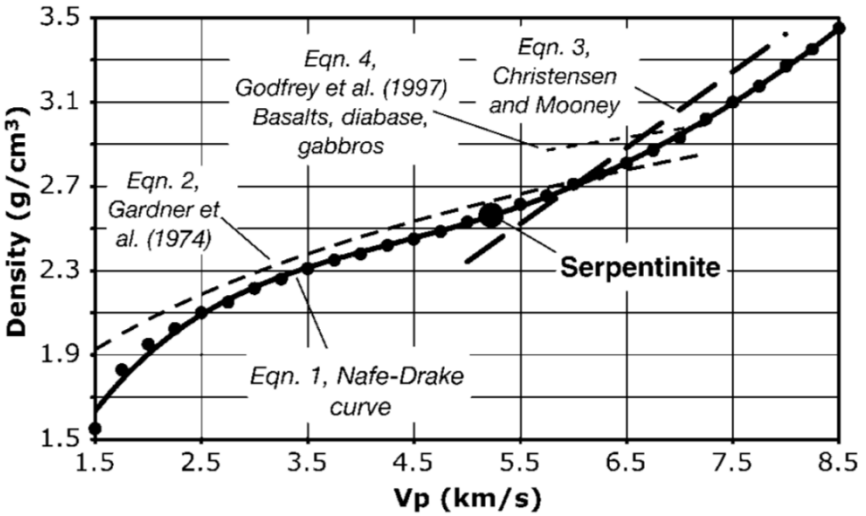
Temperature

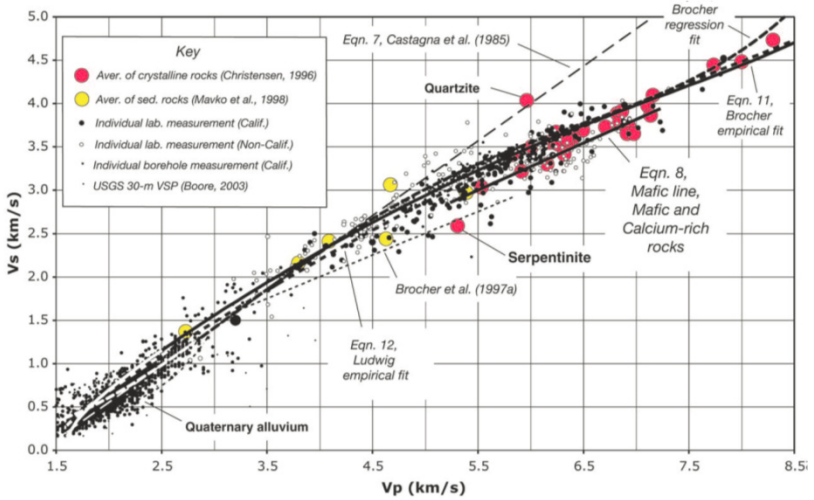
…

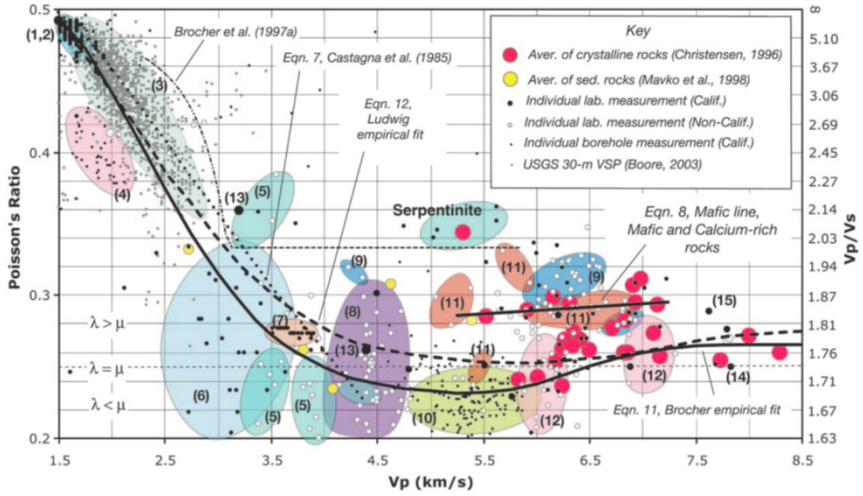


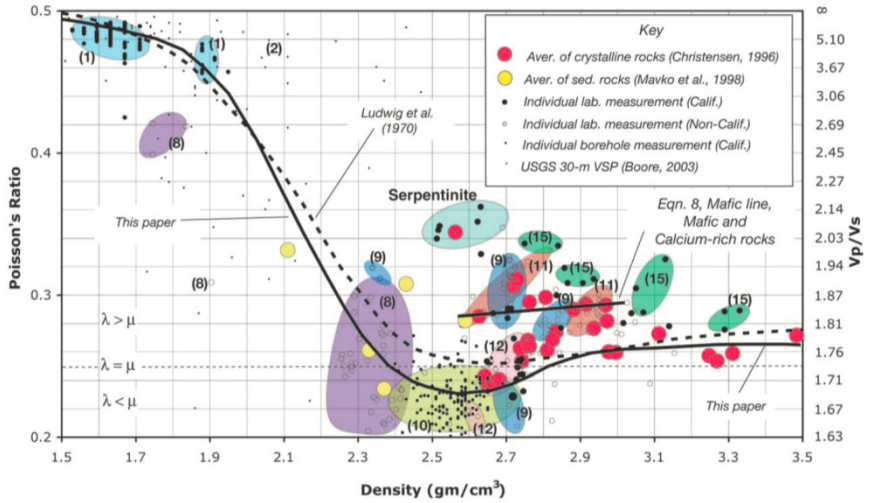


Empirical relations between elastic wavespeeds and density



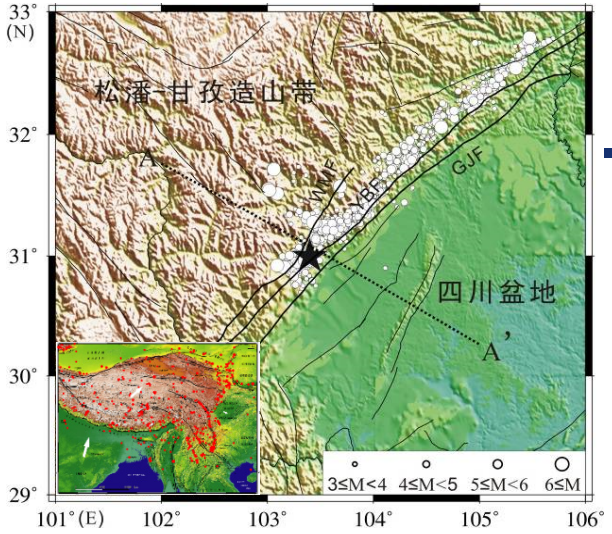


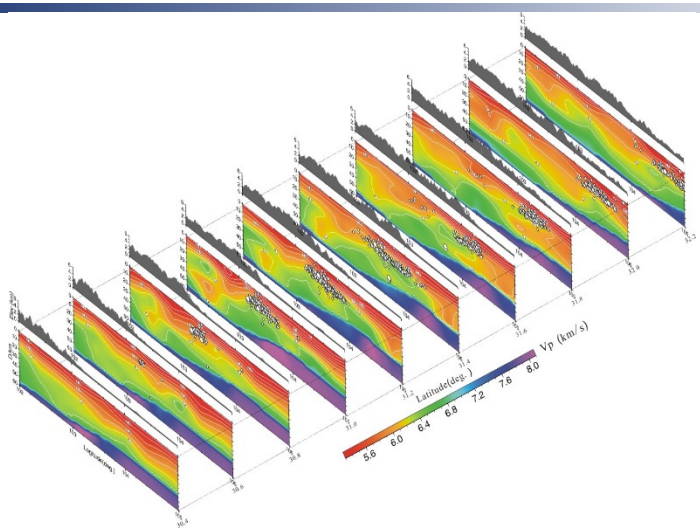




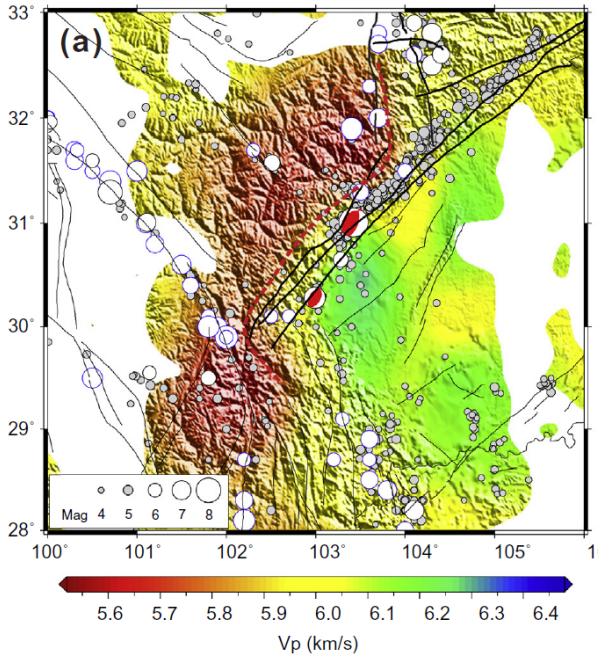
Brocher, 2005, BSSA

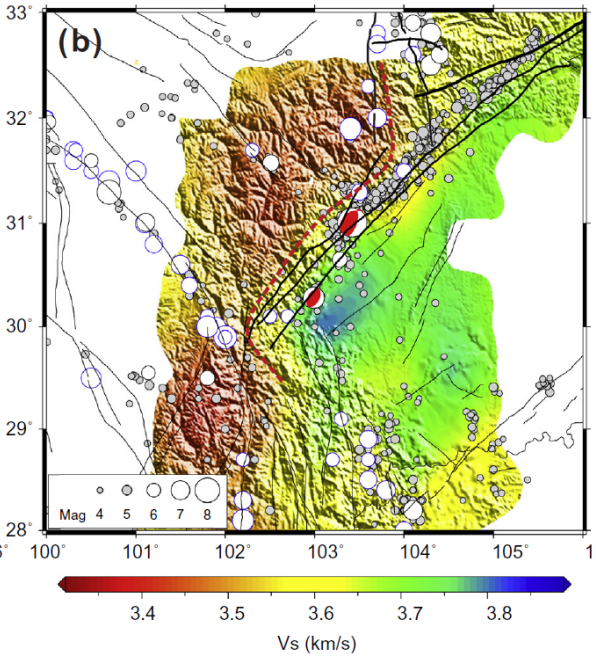
Earthquake traveltime tomography for crust and uppermost mantle

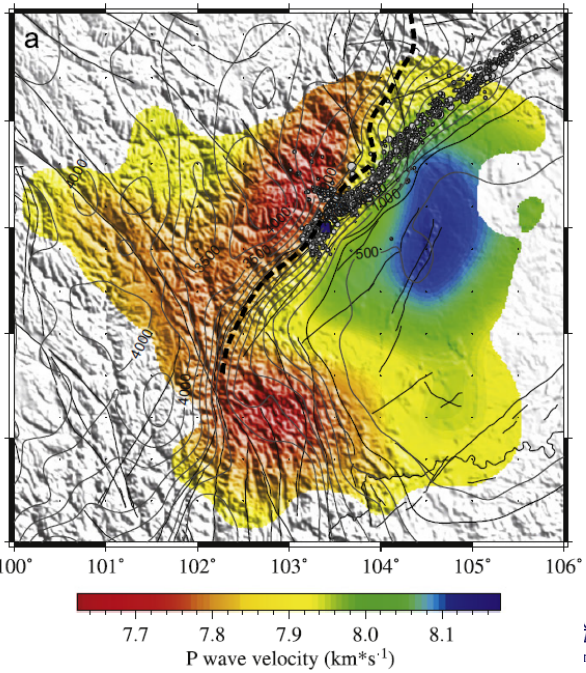




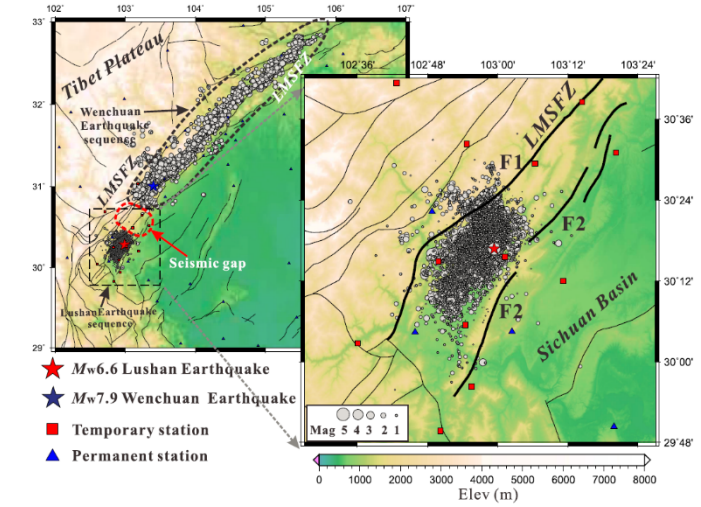
Li et al., 2012, EPSL; Li et al., 2014, PEPI

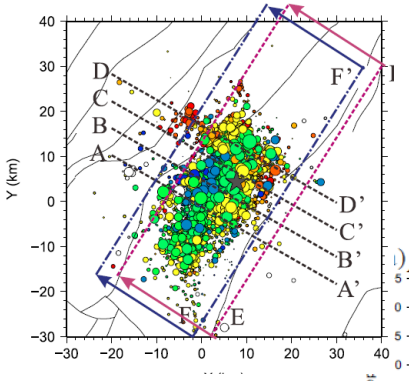


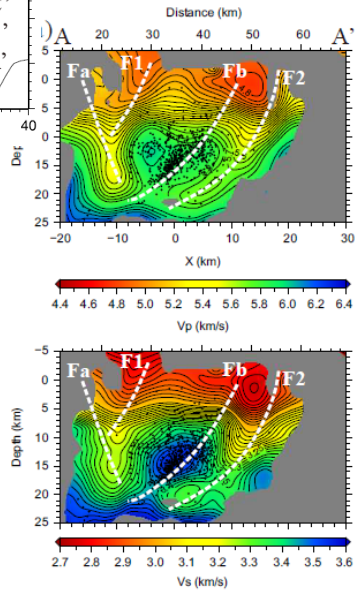


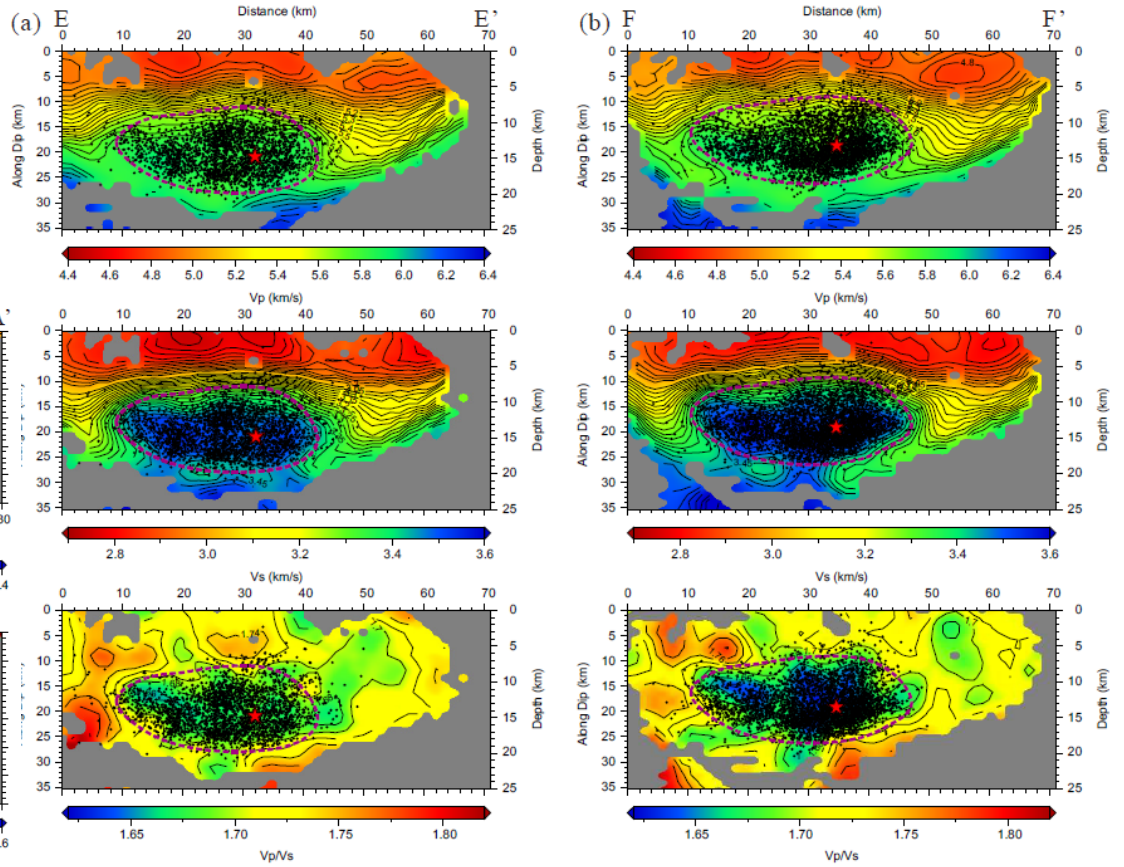


41955 first *P* and 42687 first *S* arrvials from ~7000 aftershocks









Li et al., 2013, GJI

Aftershocks within 3 months

Seismic imaging of South China Block

NCC: Late Archean

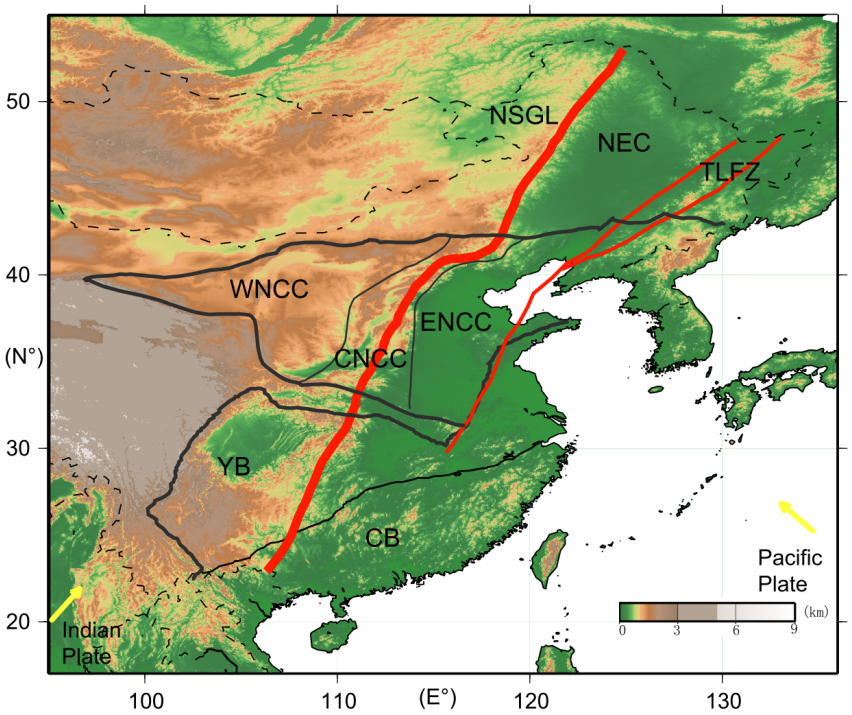
SC: Neoproterozoic

NEC: Late Mesozoic

CB: Cathaysia Block

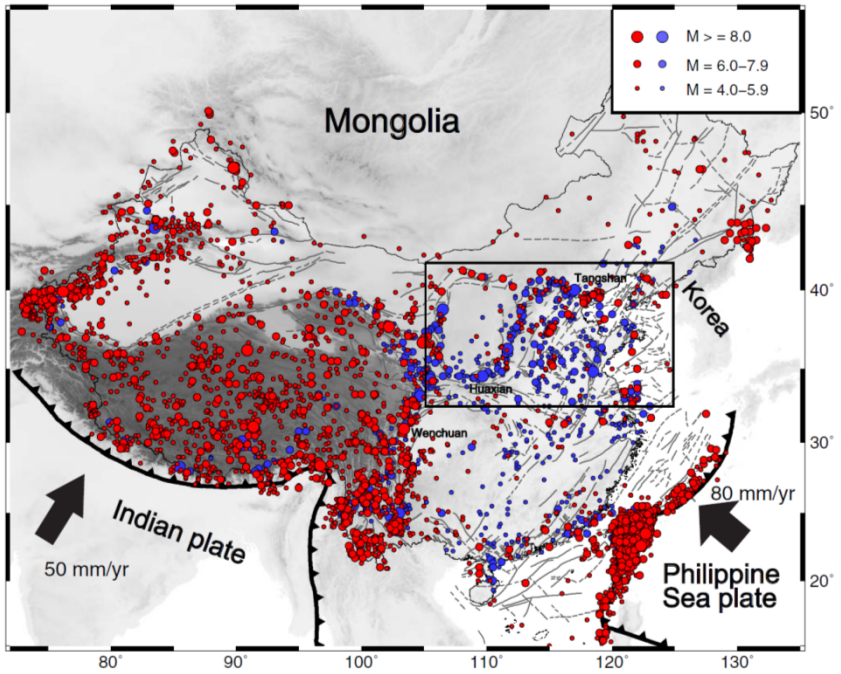
YB: Yangtze Block

(Li et al., 1993; Zhao et al., 2005; Ren et al., 2002)



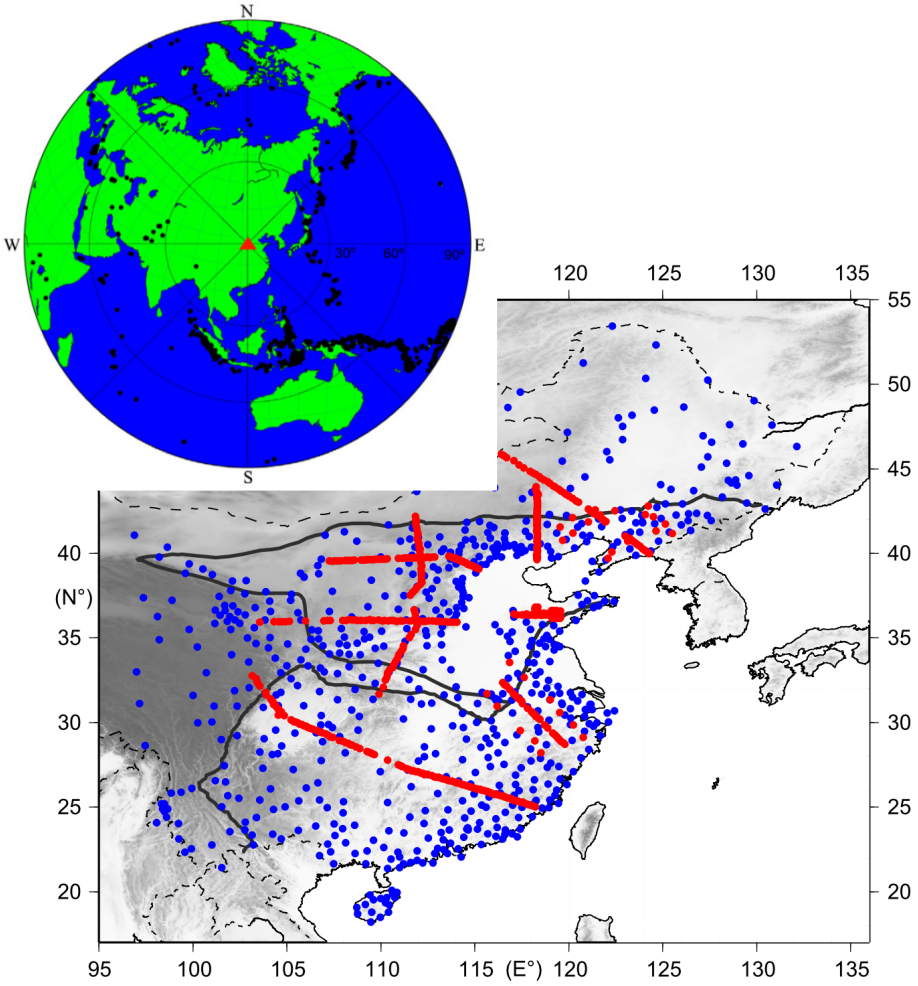
Wei et al., 2016, JAES

No enough earthquakes in South China for earthquake traveltime tomography

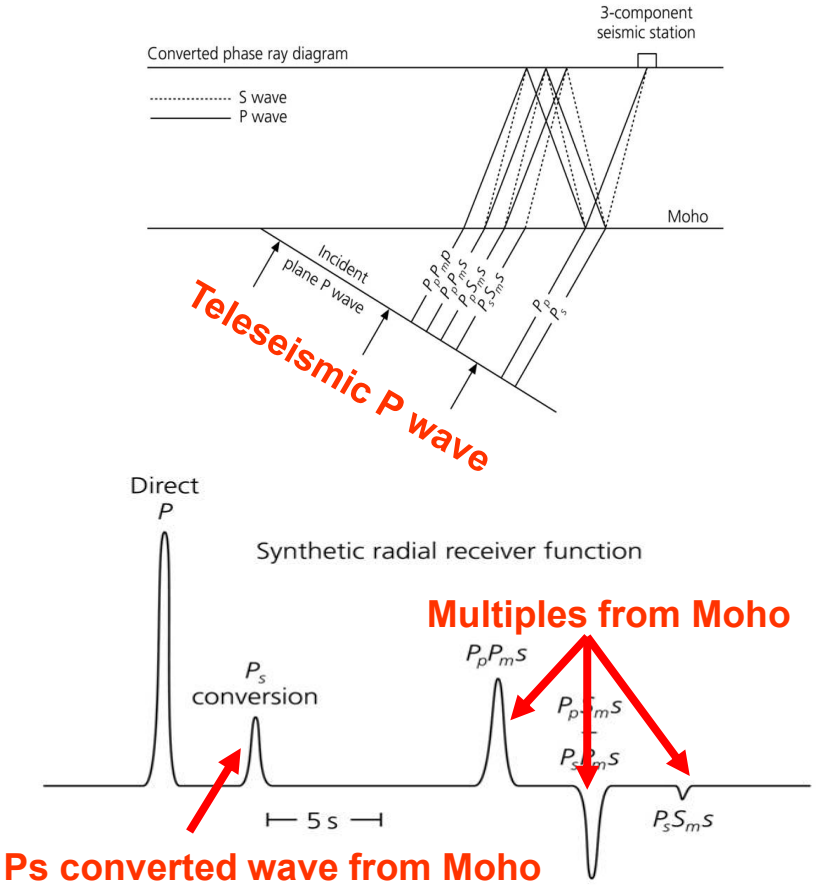


Liu & Stein, 2016, Earth-Science Reviews

Receiver function method with abundant teleseismic events (Δ ~ 30-90°)



483 temporary and 660 permanent stations

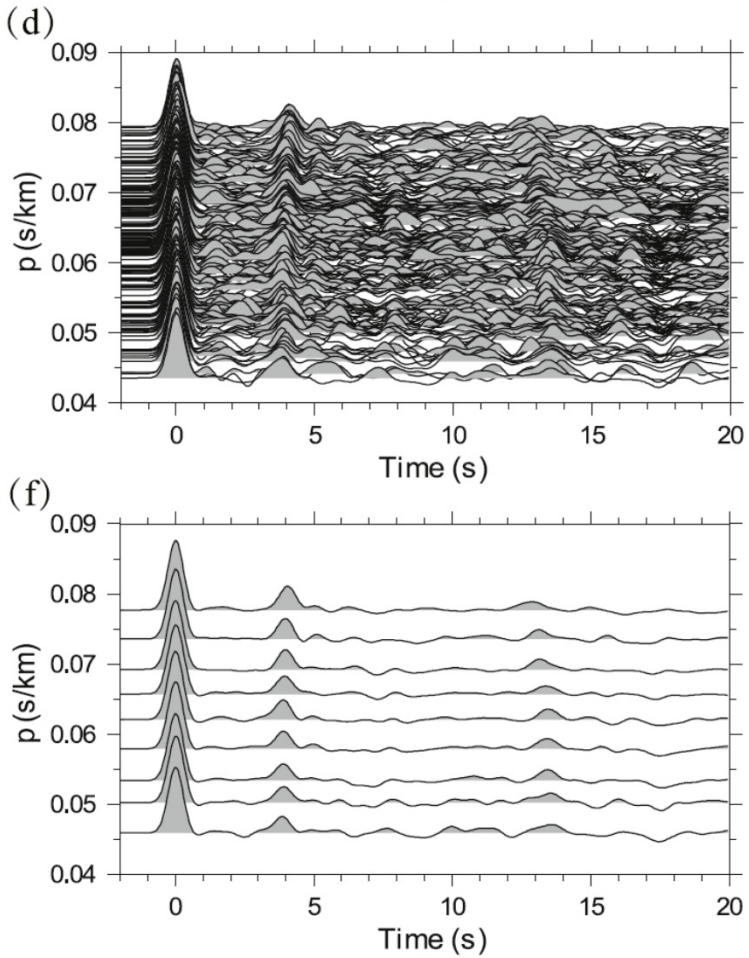


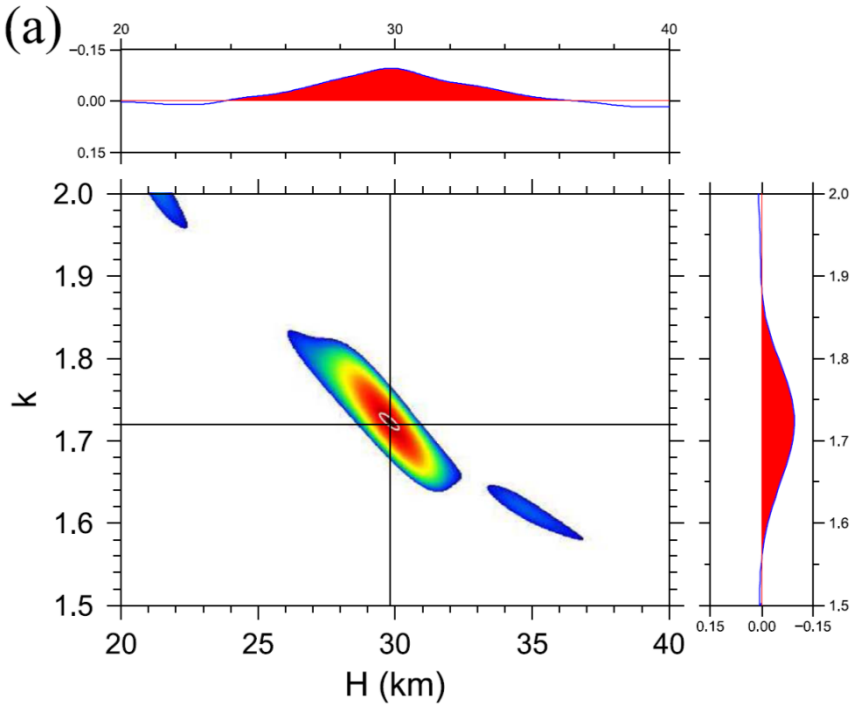
Receiver function H-κ stacking method

$$t_{Ps} = H * \left(\sqrt{\left(v_p / v_s\right)^2 - p^2 v_p^2} - \sqrt{1 - p^2 v_p^2} \right) / v_p$$

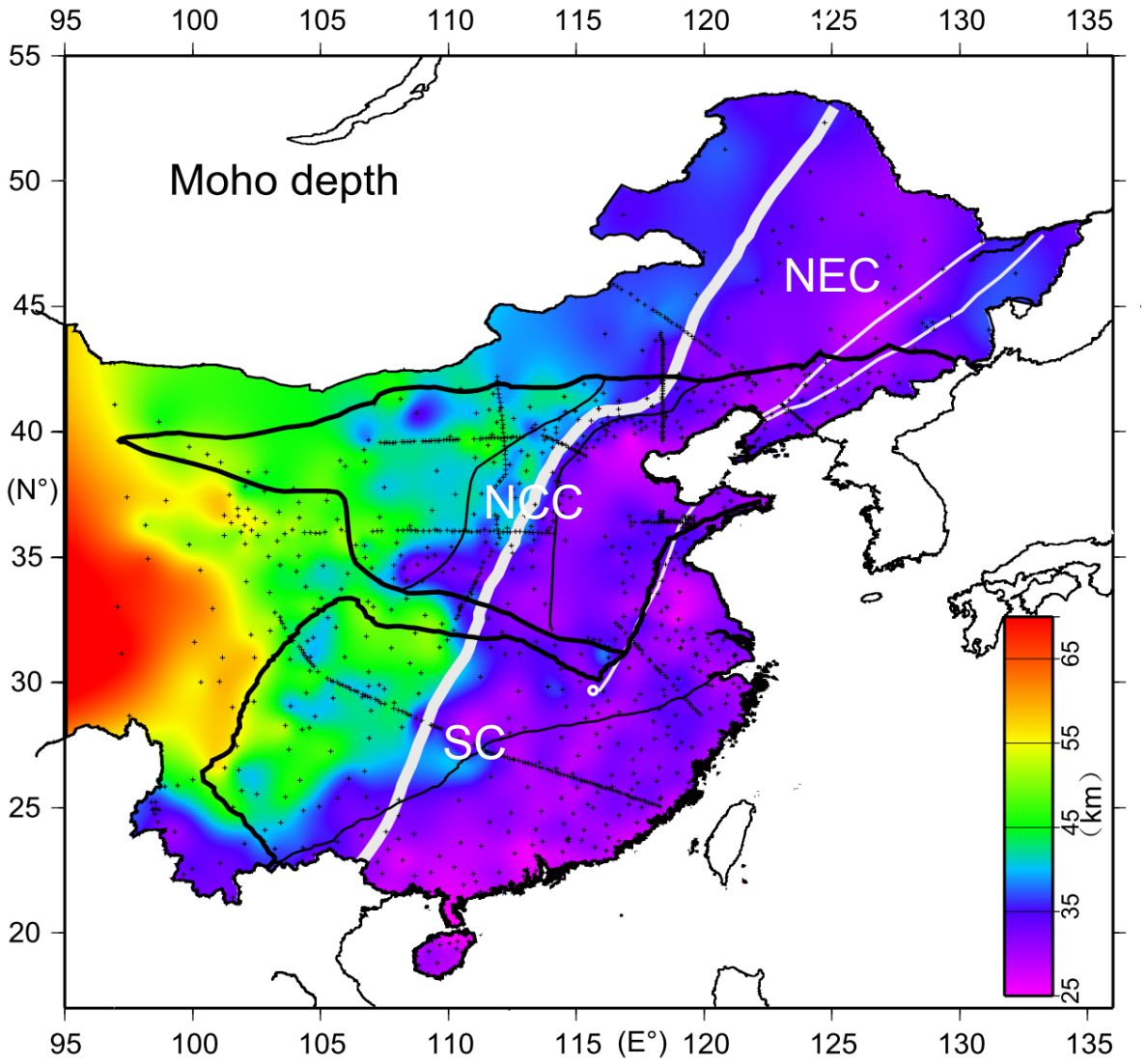
$$t_{PpPs} = H * \left(\sqrt{\left(v_p / v_s\right)^2 - p^2 v_p^2} + \sqrt{1 - p^2 v_p^2} \right) / v_p$$

$$t_{PpSs} = 2H * \left(\sqrt{\left(v_p / v_s\right)^2 - p^2 v_p^2} \right) / v_p$$





Crustal thickness



E-W thickening

NEC: <40 km

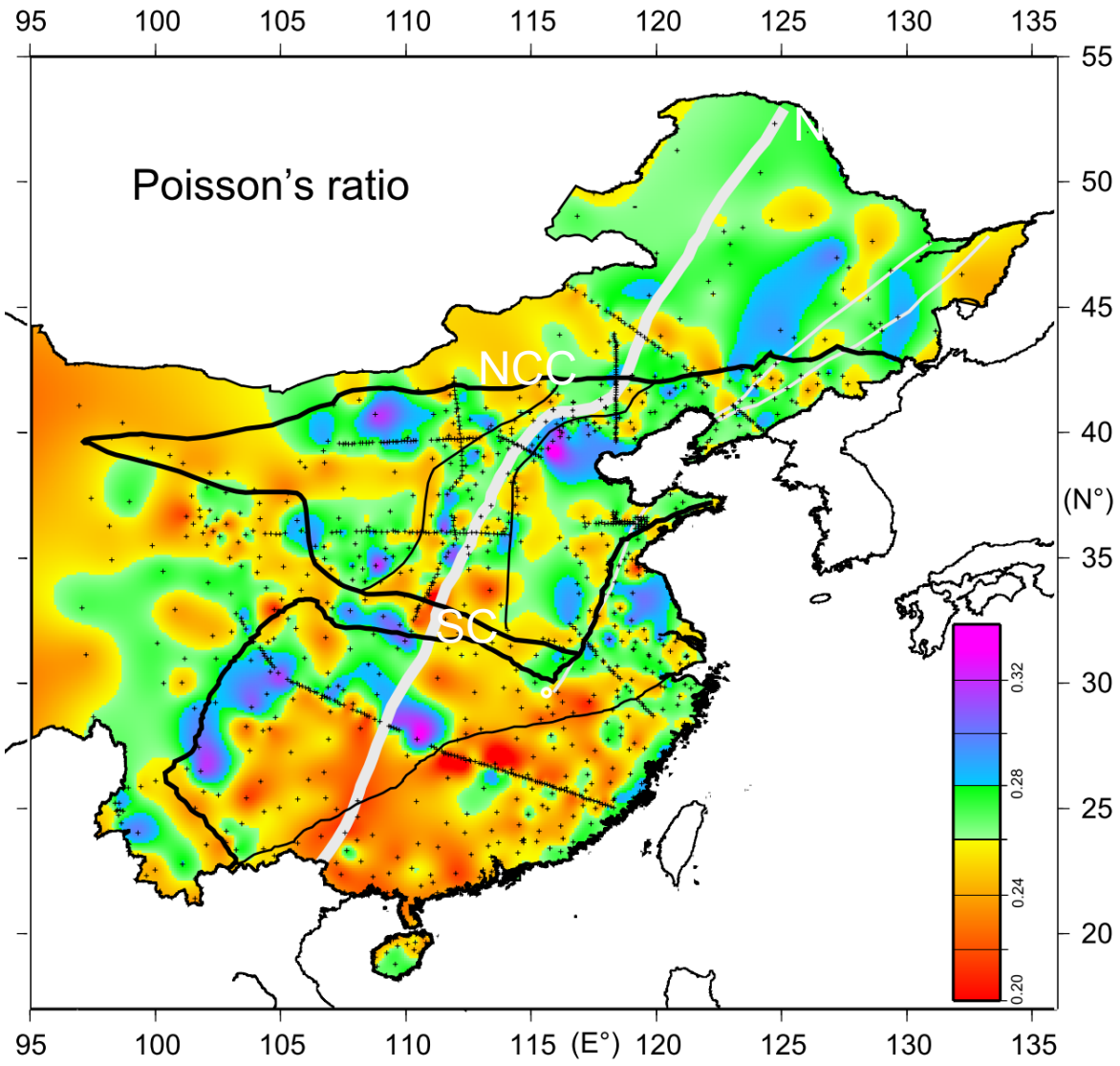
NCC: east <35 km

west 35-50 km

SC: east <35 km

west 35-50 km

Poisson's ratio



Complicated variation

High anomaly：tectonic boundaries…

Low anomaly：Cathaysia Block…

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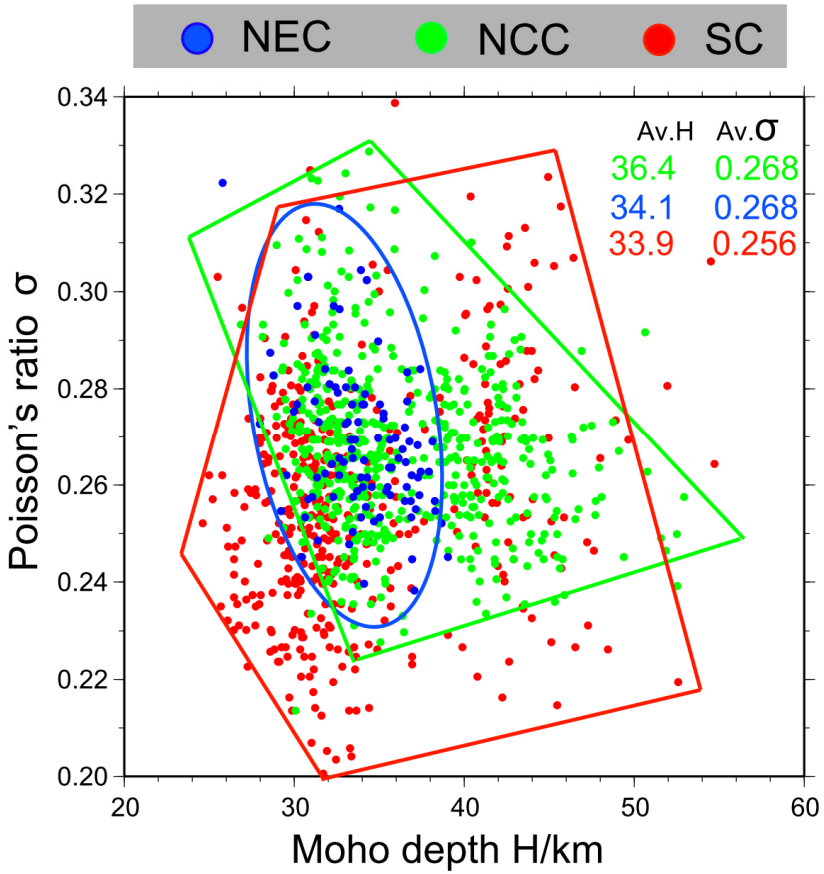
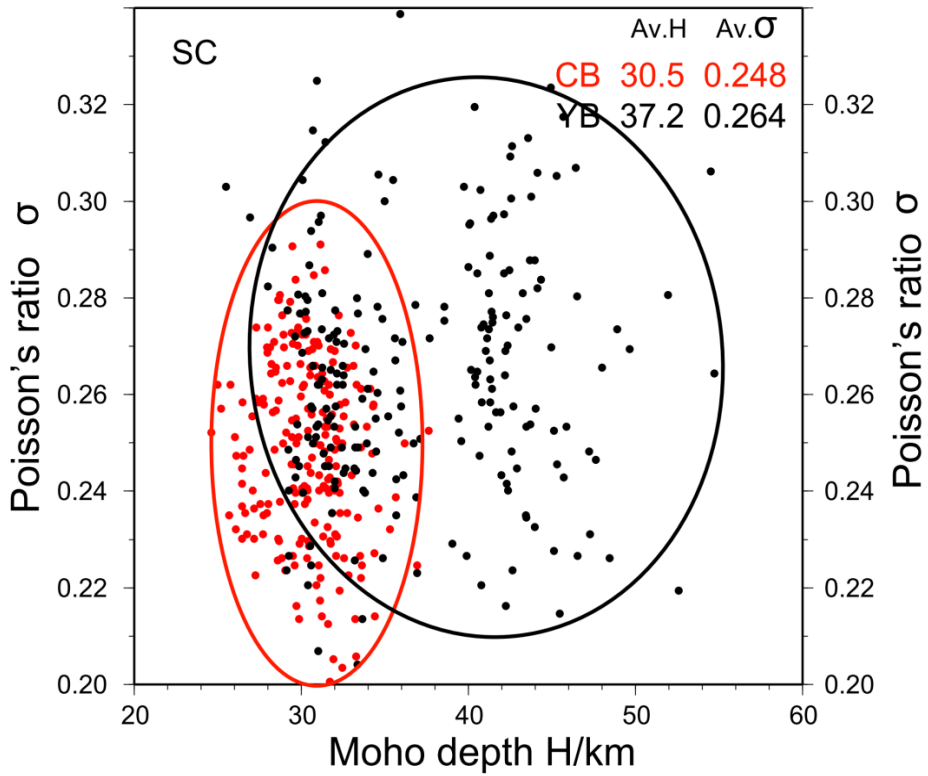
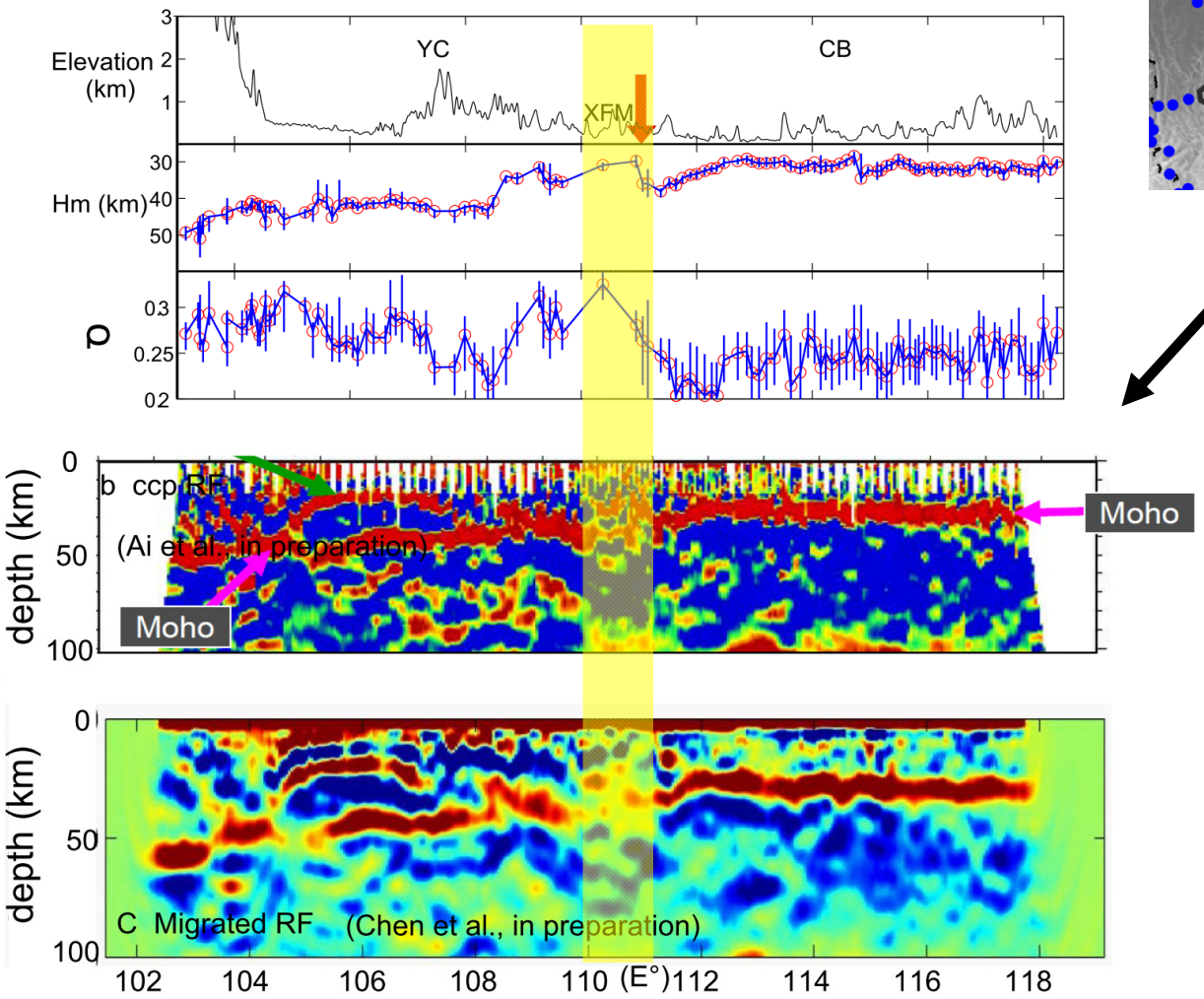
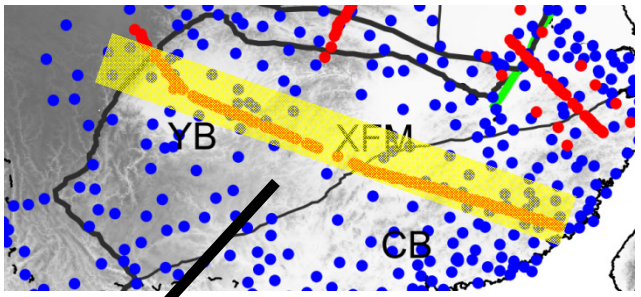
Characteristics of Crustal thickness and Poisson's ratio





Xuefeng Mountains: deep boundary





Striking variation

E-W difference

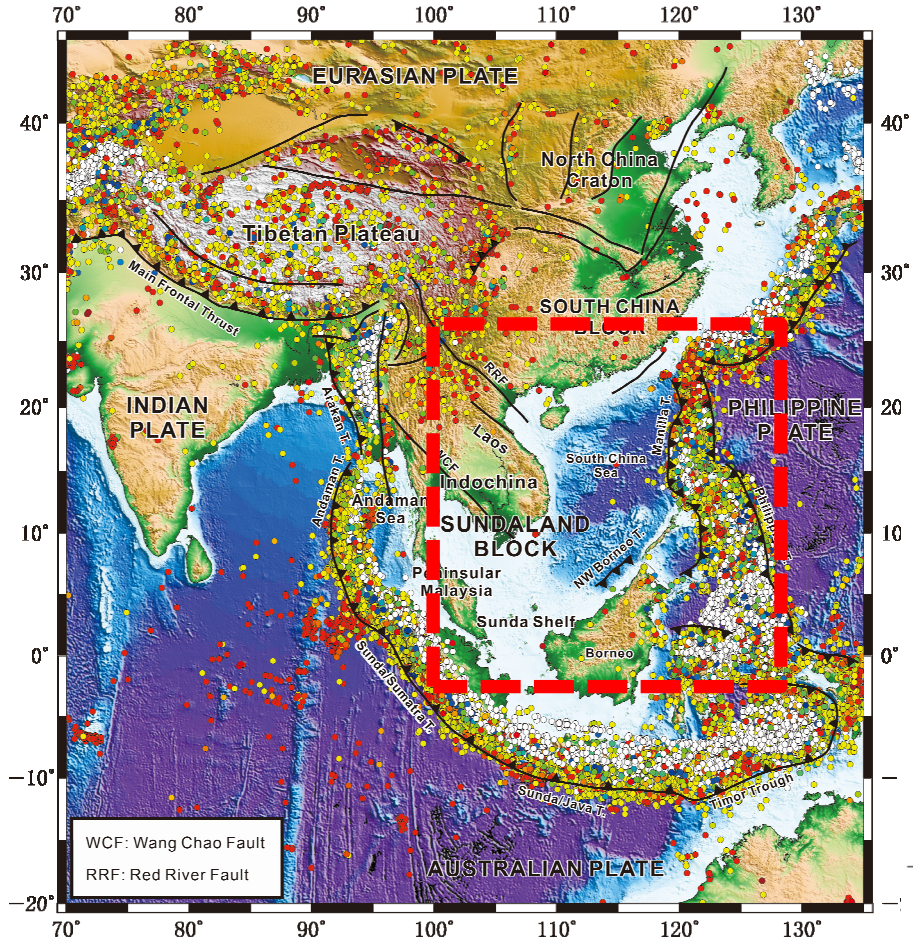
YB: Yangtze Block

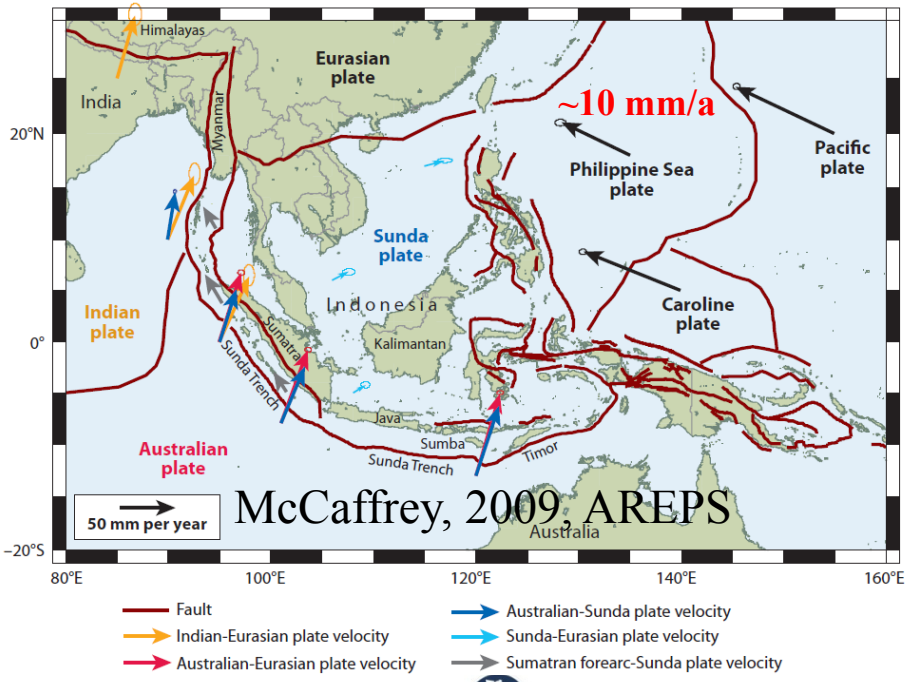
CB: Cathaysia Block

XFM: Xuefeng Mountains

Seismic imaging of South China Sea

South China Sea is the largest marginal sea of the West Pacific, which is located within the plate triple-junction and connects the Pacific Eurasian and Indo-Australian plates.





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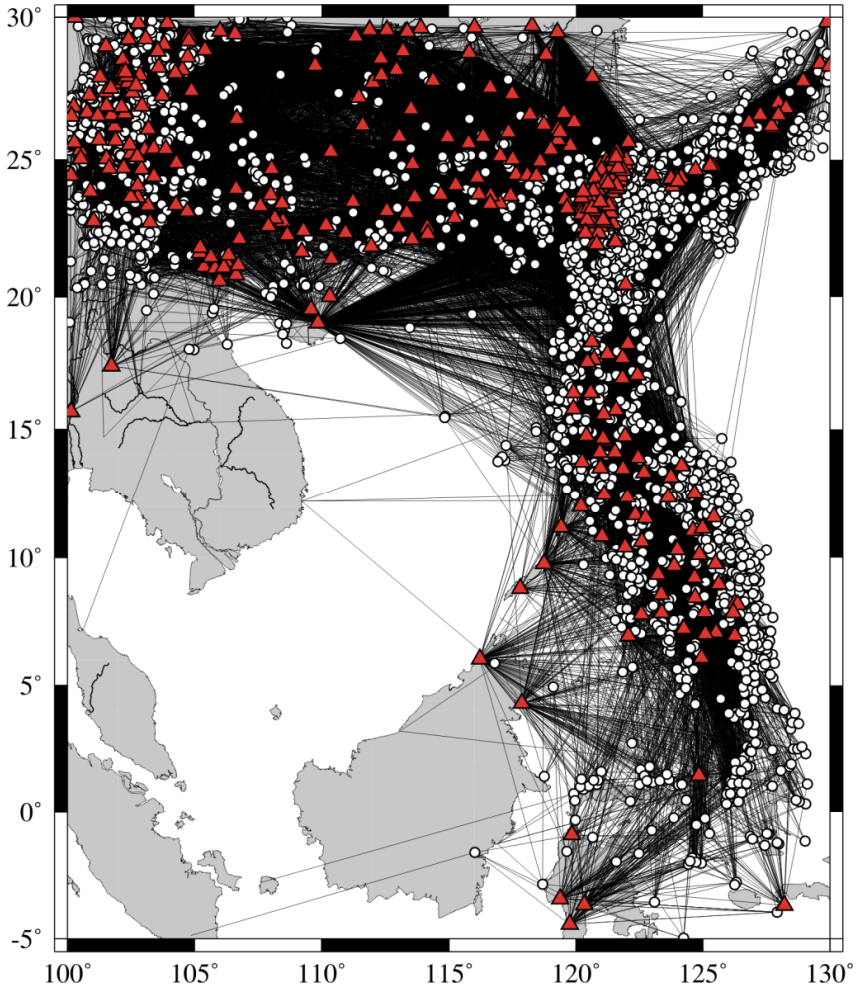
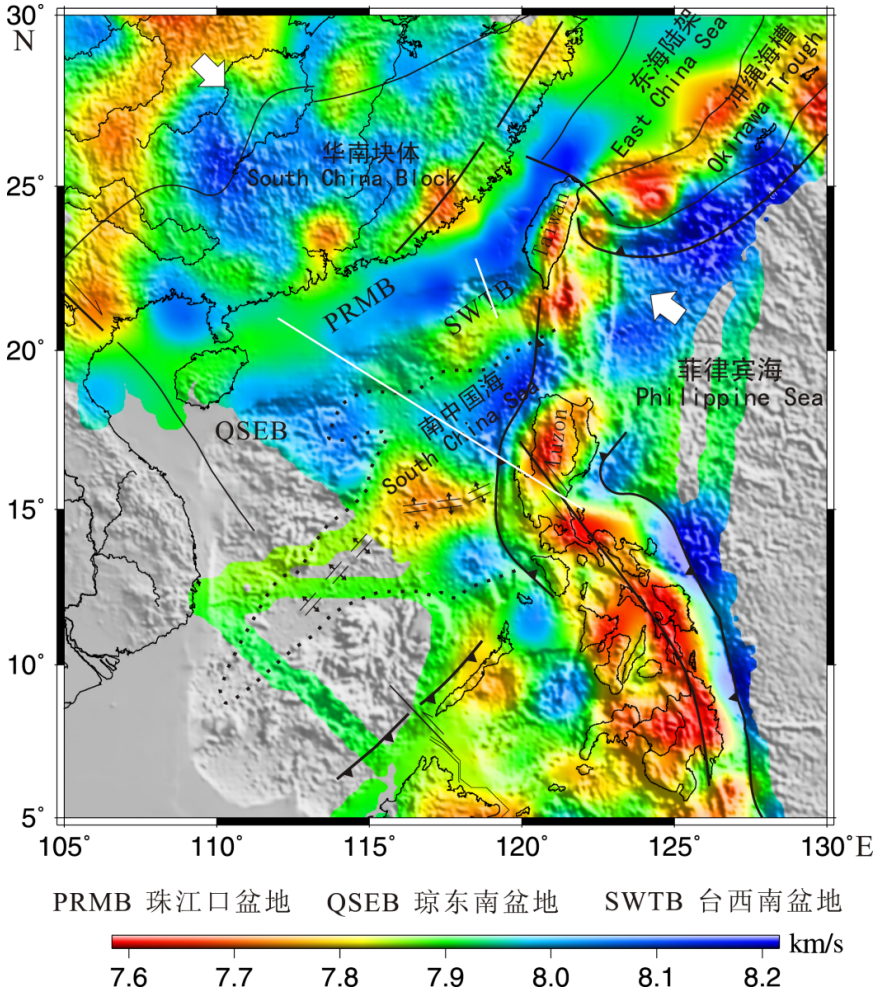
Absence of stations and earthquake events inside South China Sea



Seismic stations, earthquakes and body wave raypaths

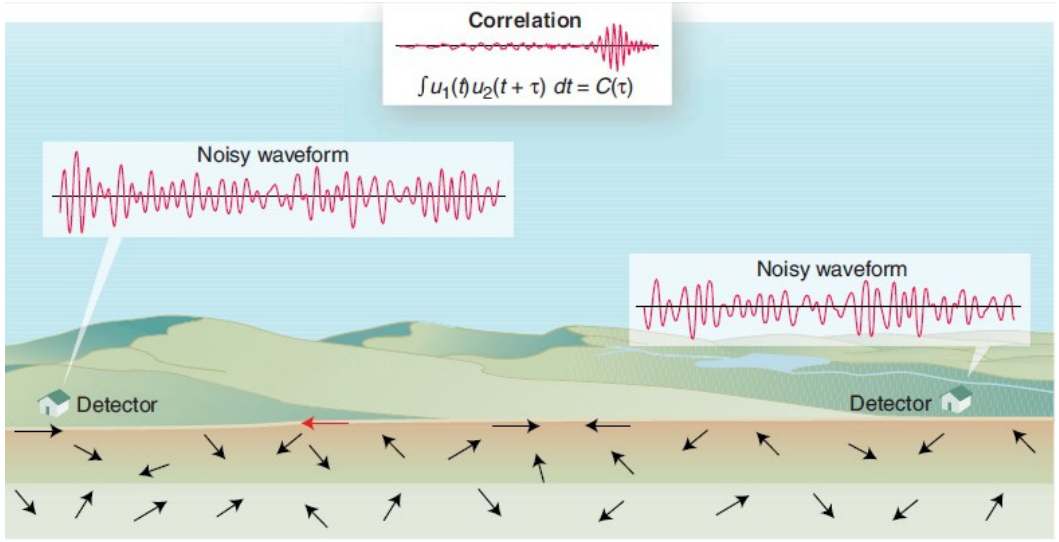


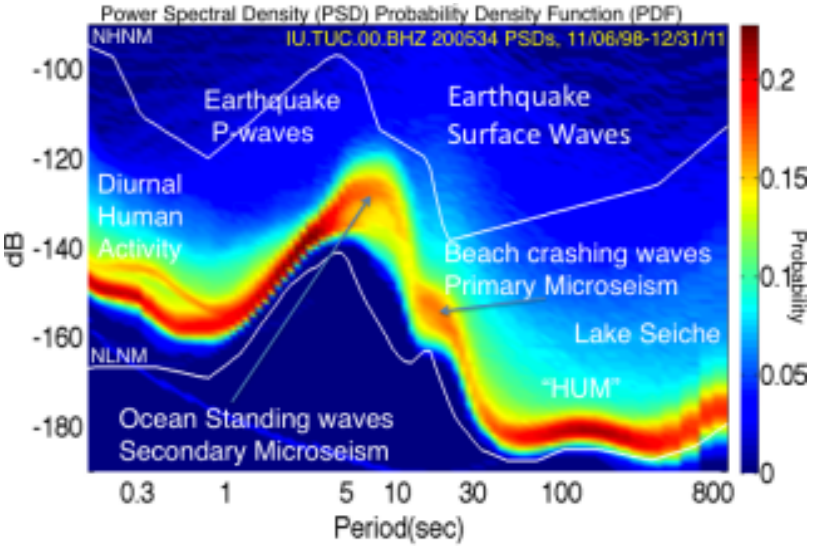
Xu et al., 2007; Hao et al., 2008

Uppermost mantle structures

Ambient noise surface wave tomography

Surface waves (and body waves) can be extracted from cross-correlations at two stations with continuous ambient noise waveform, which makes tomography feasible for a specific region covered by seismic array.

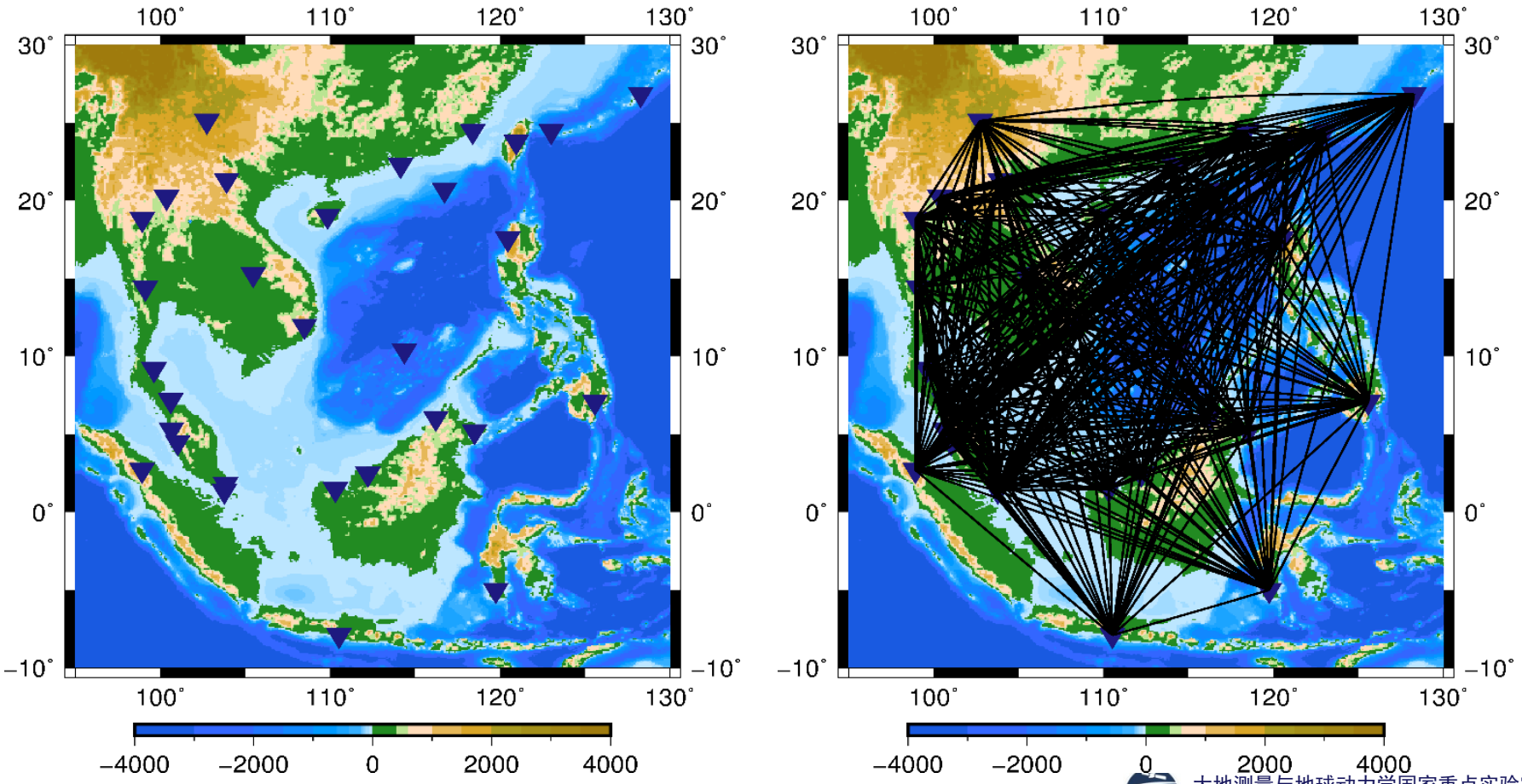




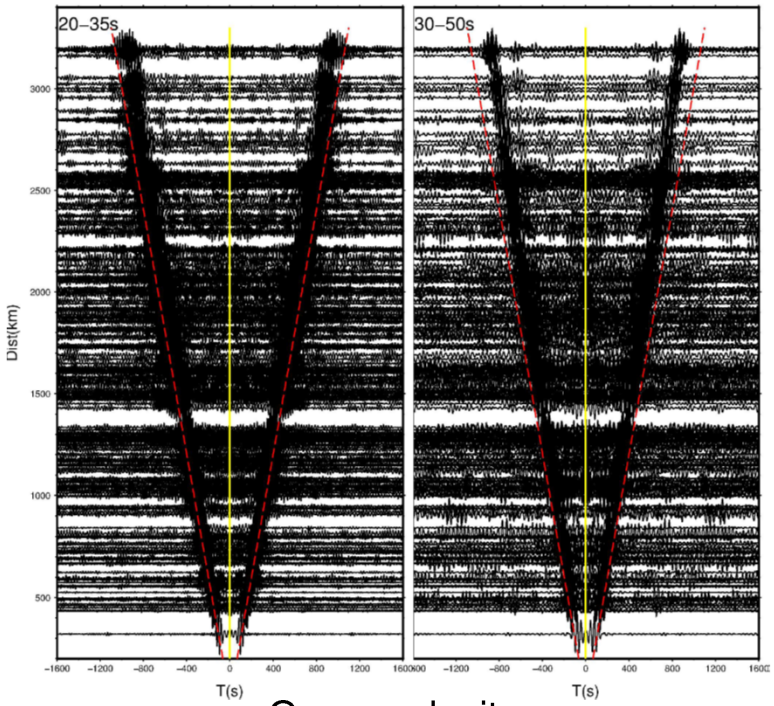
Weaver., 2005, Science

31 selected seismic stations with 6-year continuous waveforms are processed.

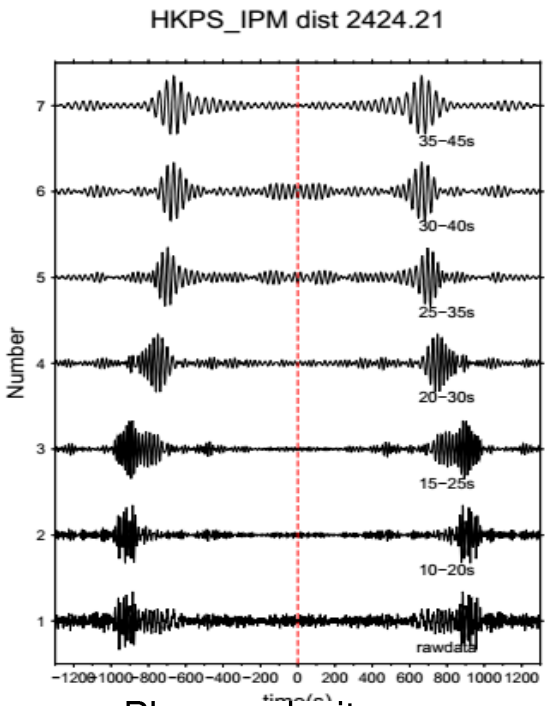
Good raypath coverage is obtained around South China Sea



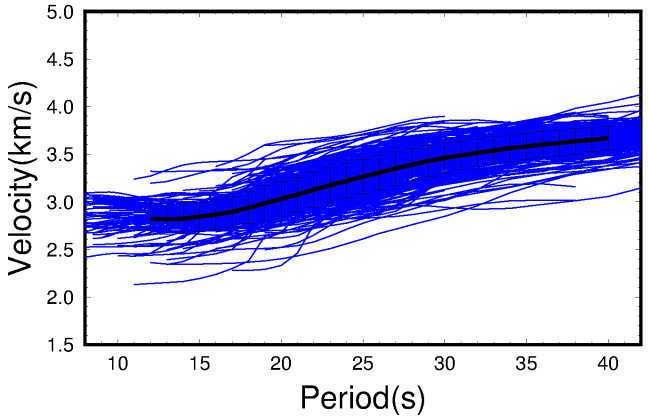
347 Group and Phase dispersion curves

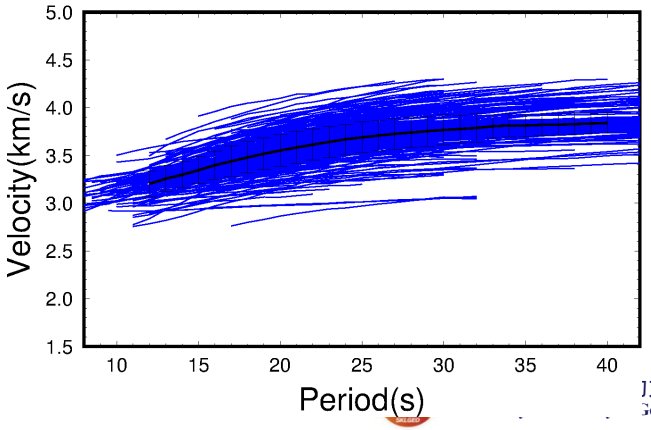


Group velocity

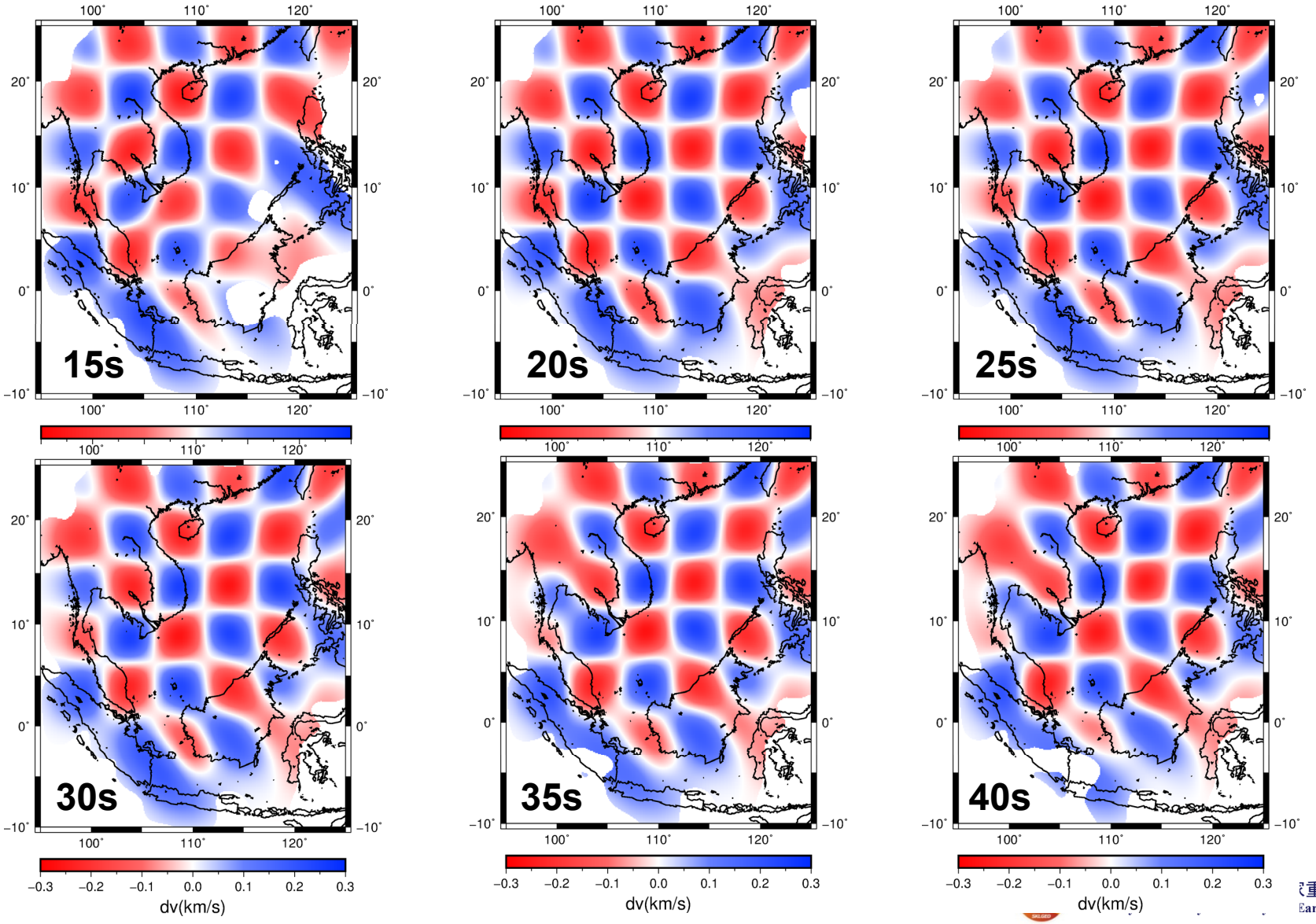


Phase velocity

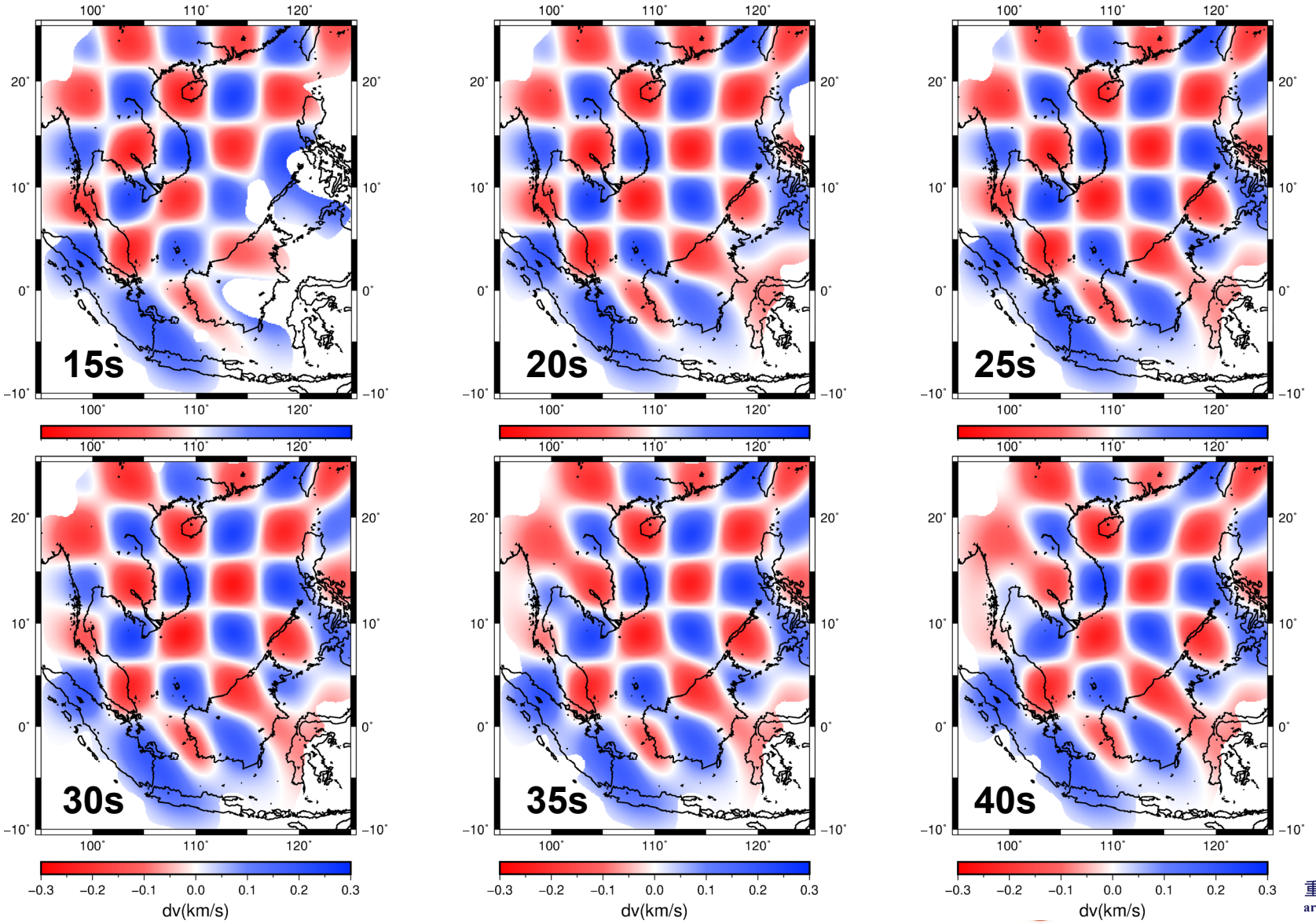




Resolution tests for group velocity tomography

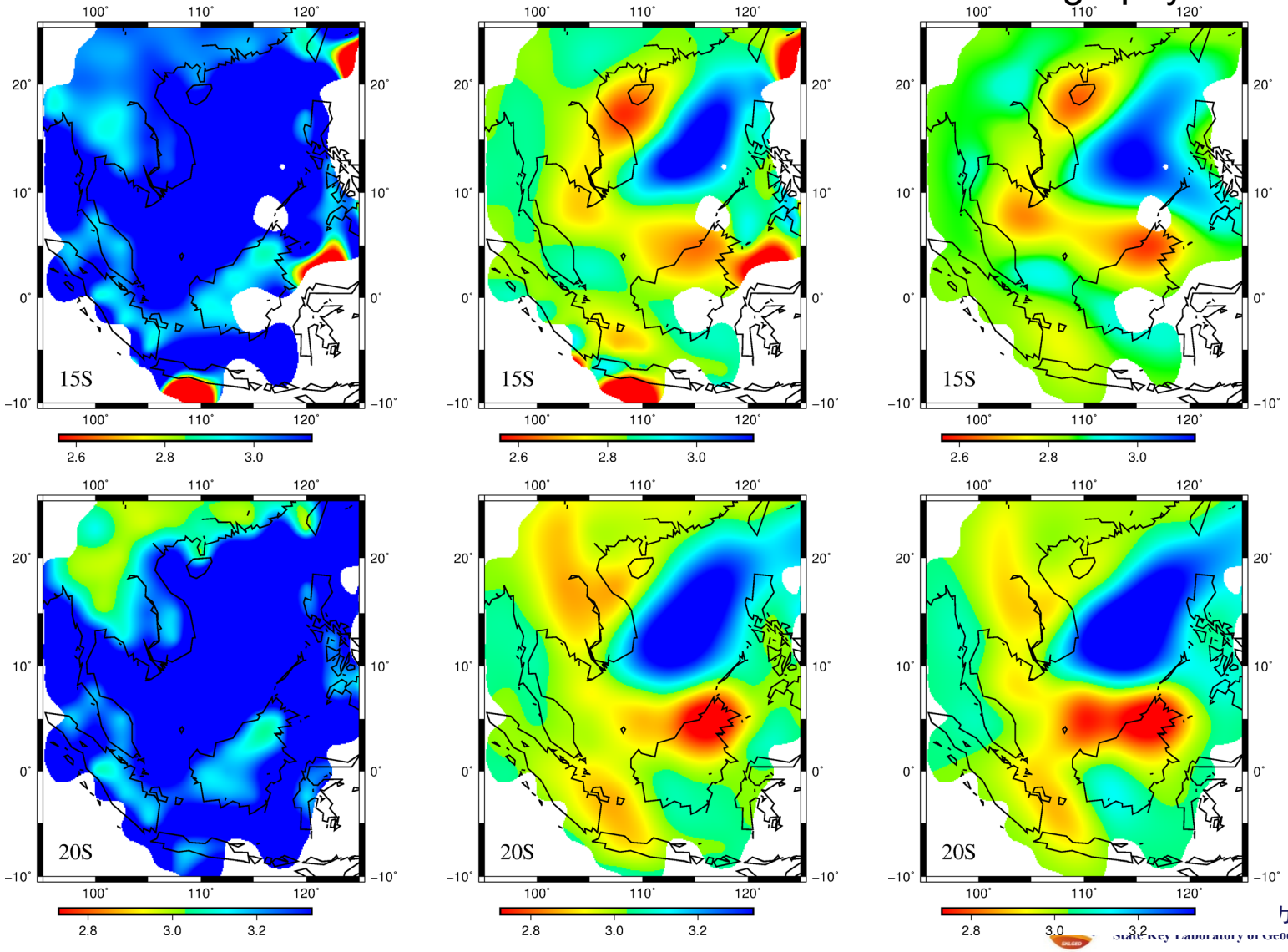


Resolution tests for phase velocity tomography



Group velocity maps at 15 and 20 s period

CRUST1.0 | Inverted model | Tomography



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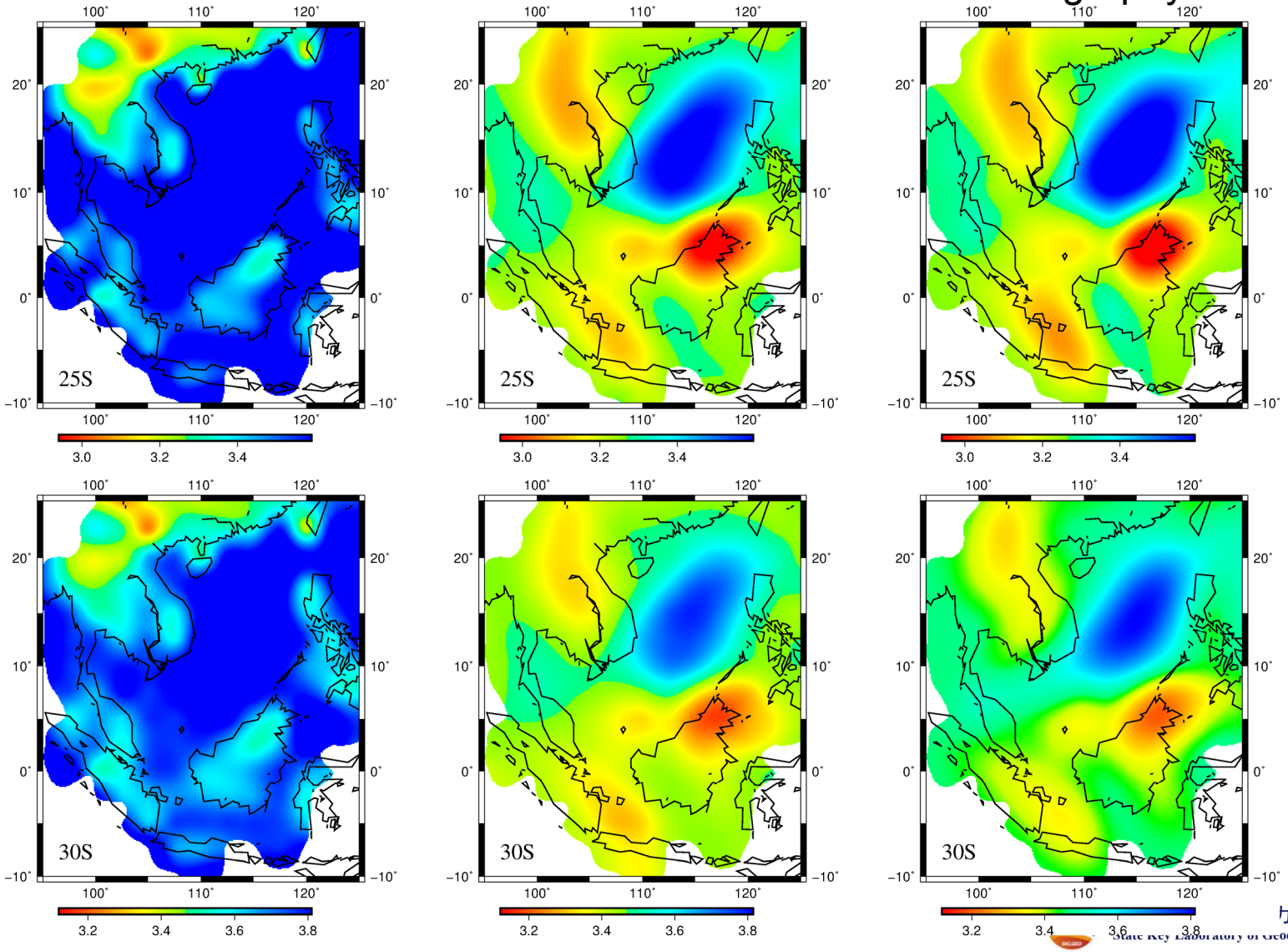
Group velocity maps at 25 and 30 s period

CRUST1.0 | Inverted model | Tomography



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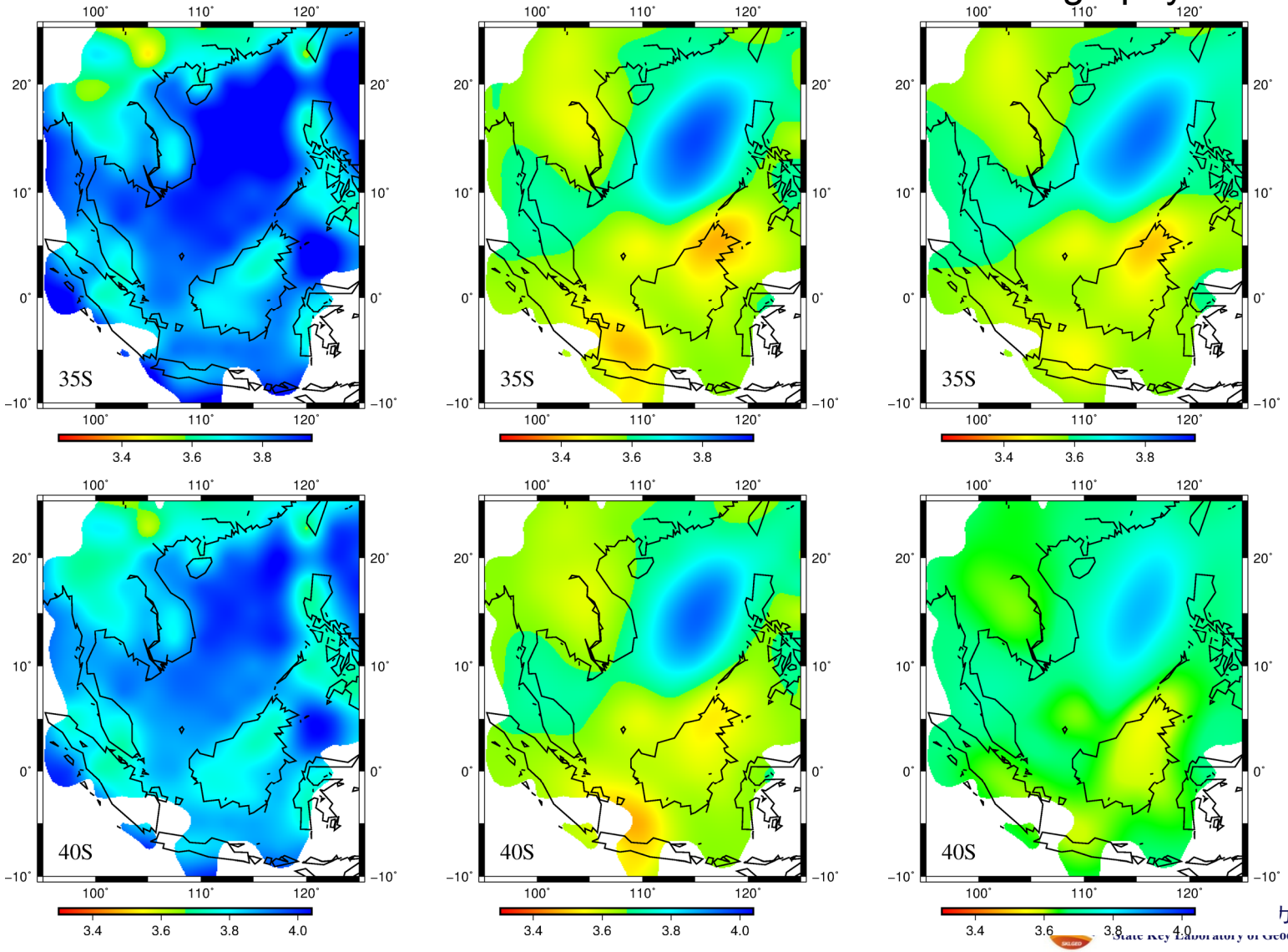
Group velocity maps at 35 and 40 s period

CRUST1.0 | Inverted model | Tomography



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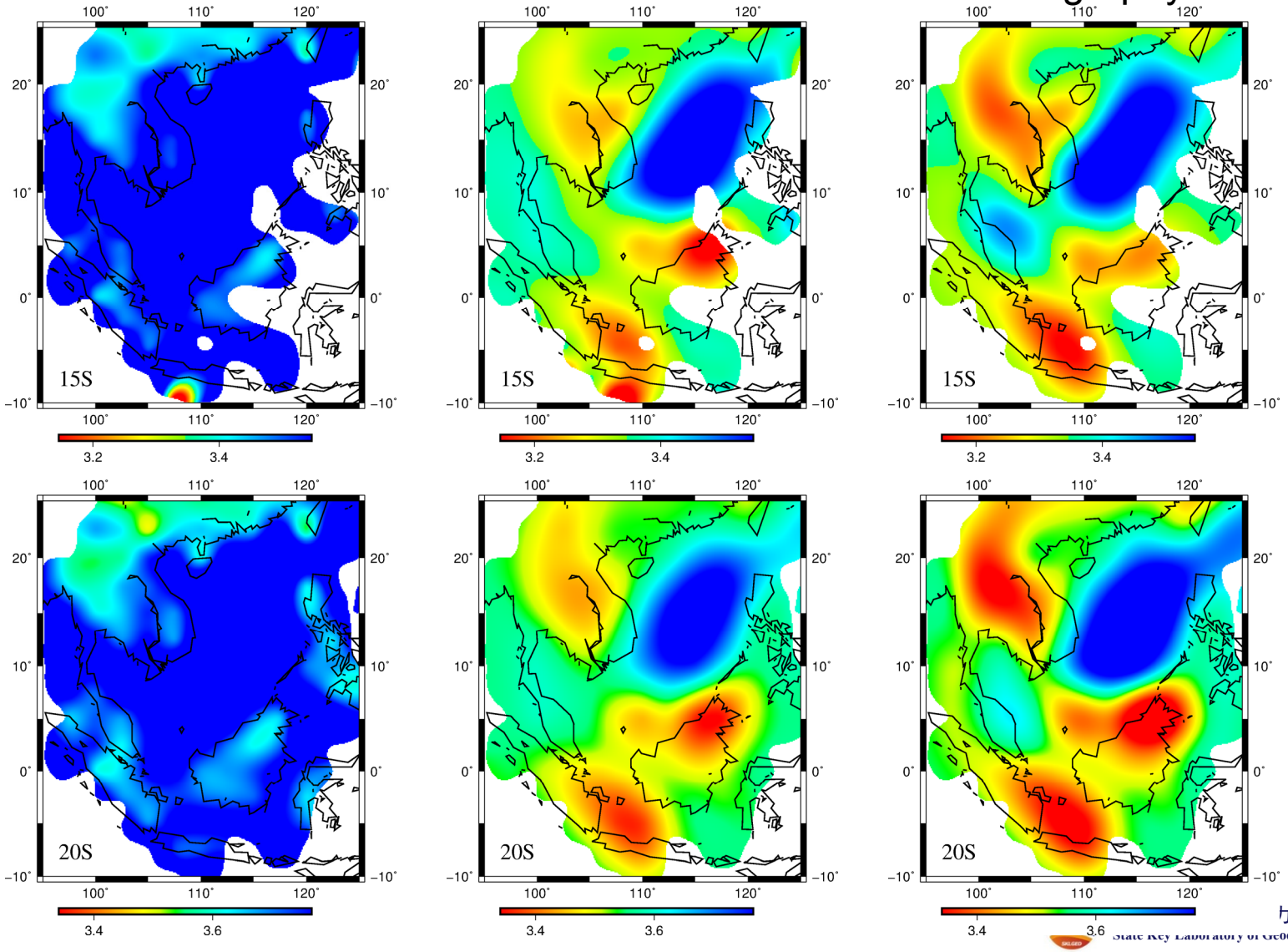
Phase velocity maps at 15 and 20 s period

CRUST1.0 | Inverted model | Tomography



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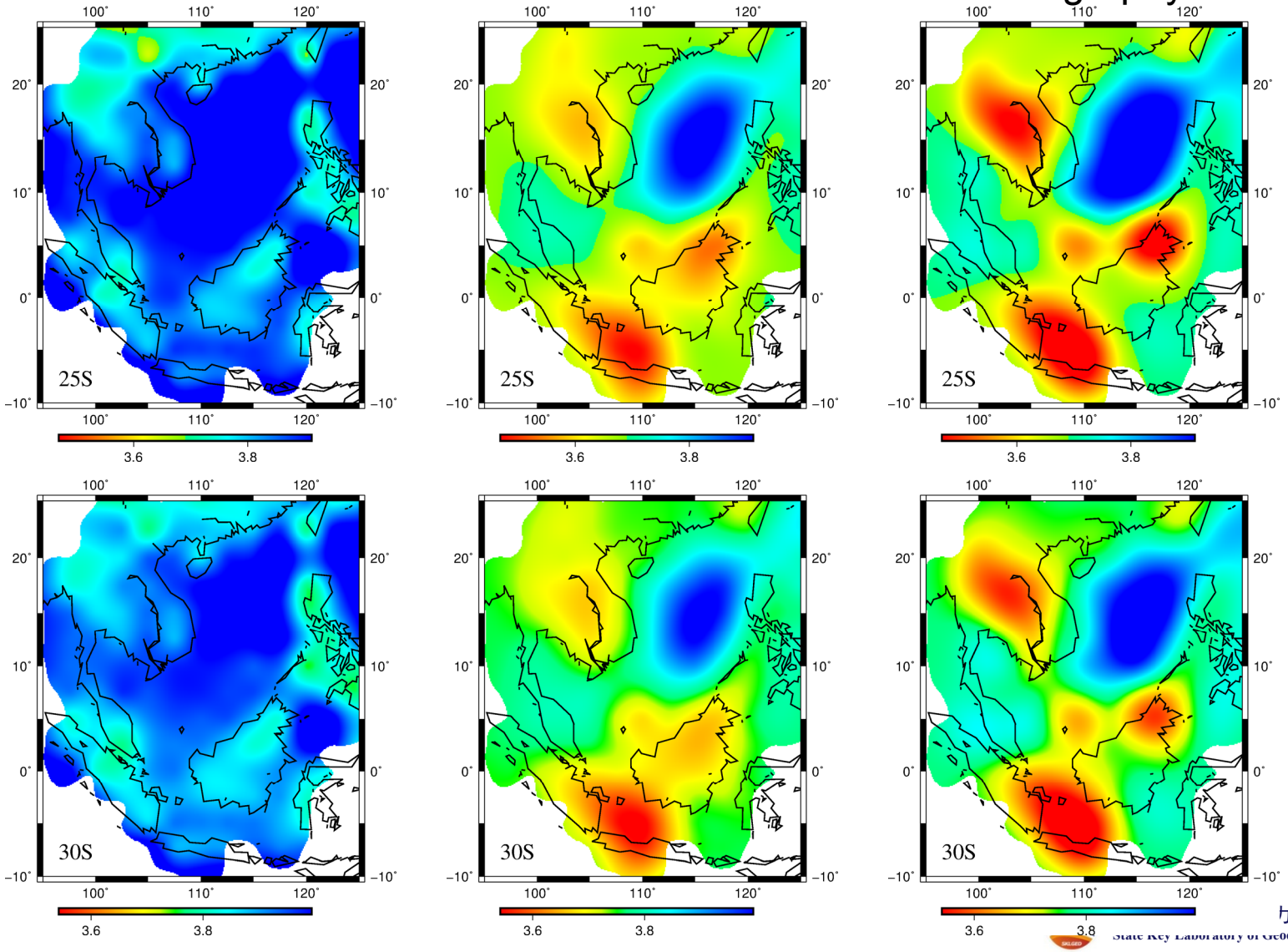
Phase velocity maps at 25 and 30 s period

CRUST1.0 | Inverted model | Tomography



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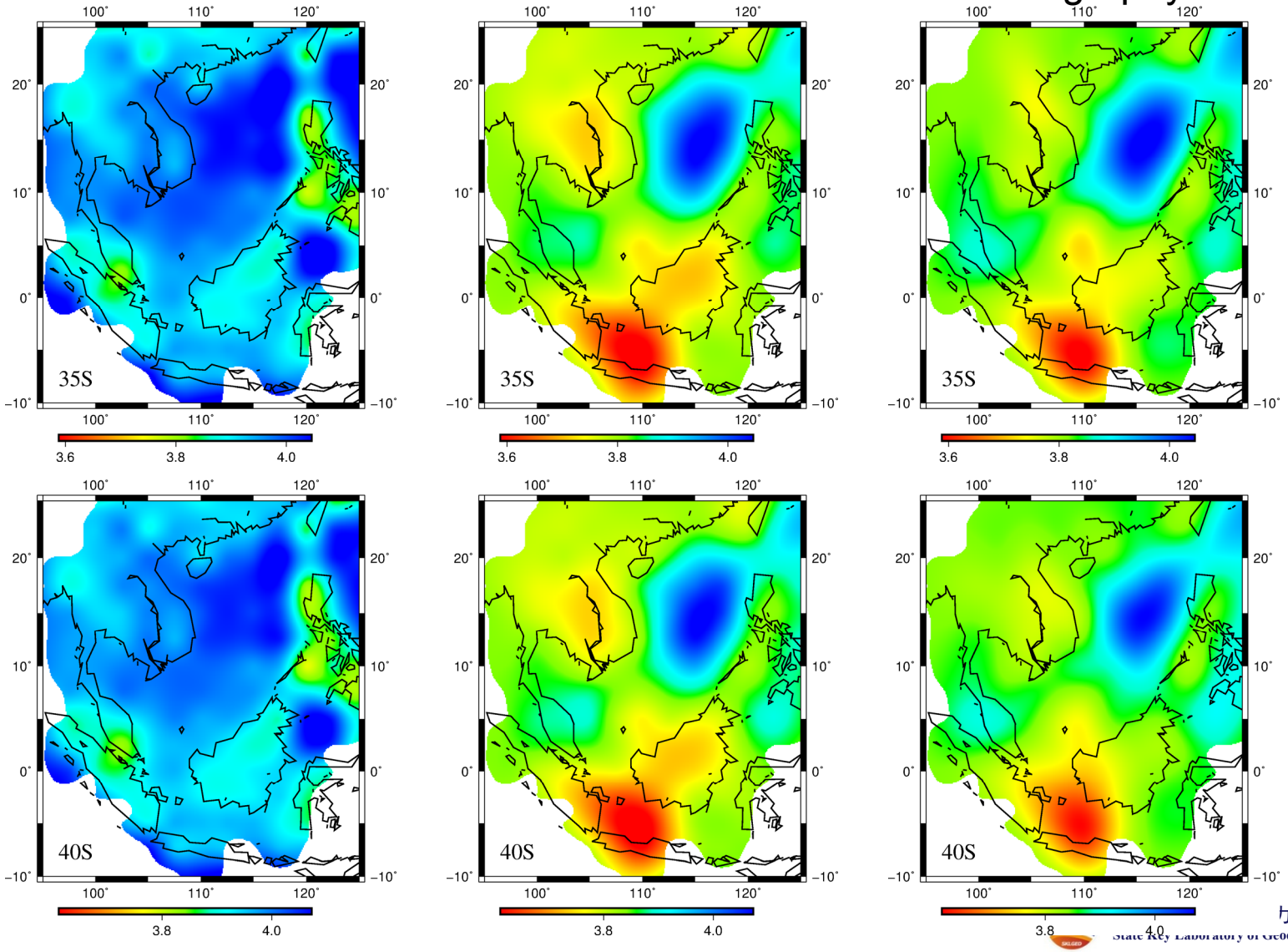
Phase velocity maps at 35 and 40 s period

CRUST1.0 | Inverted model | Tomography



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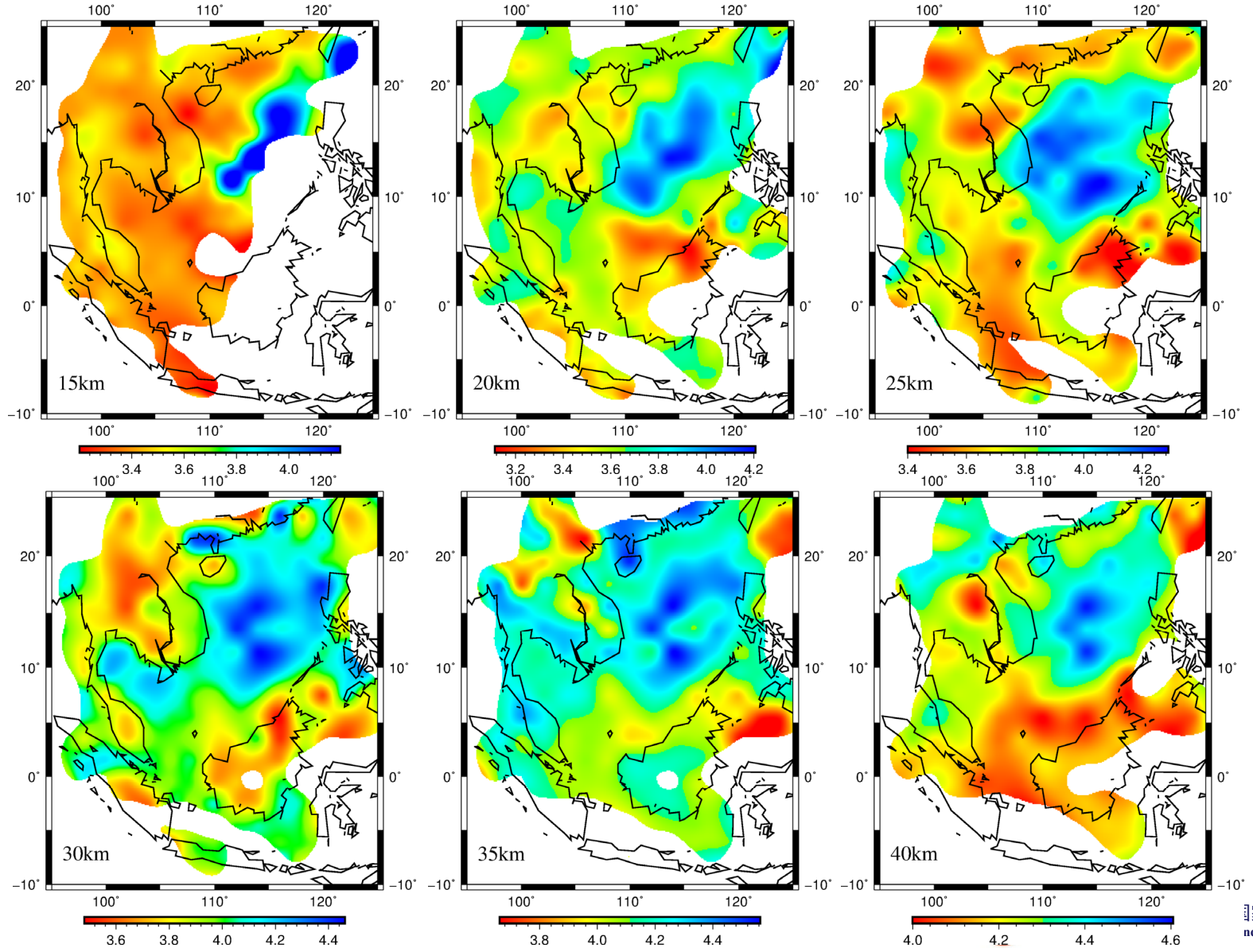
3-D Shear-wave velocity structures of SCS



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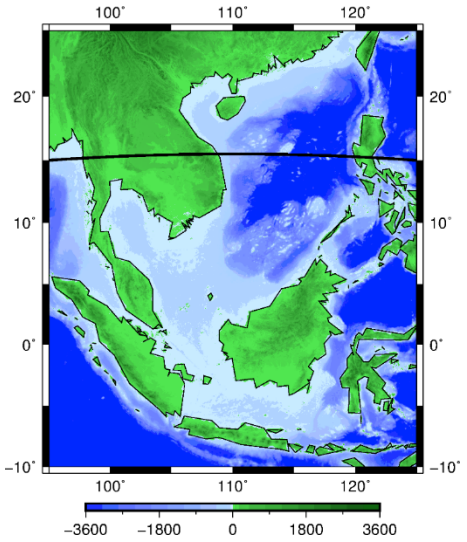
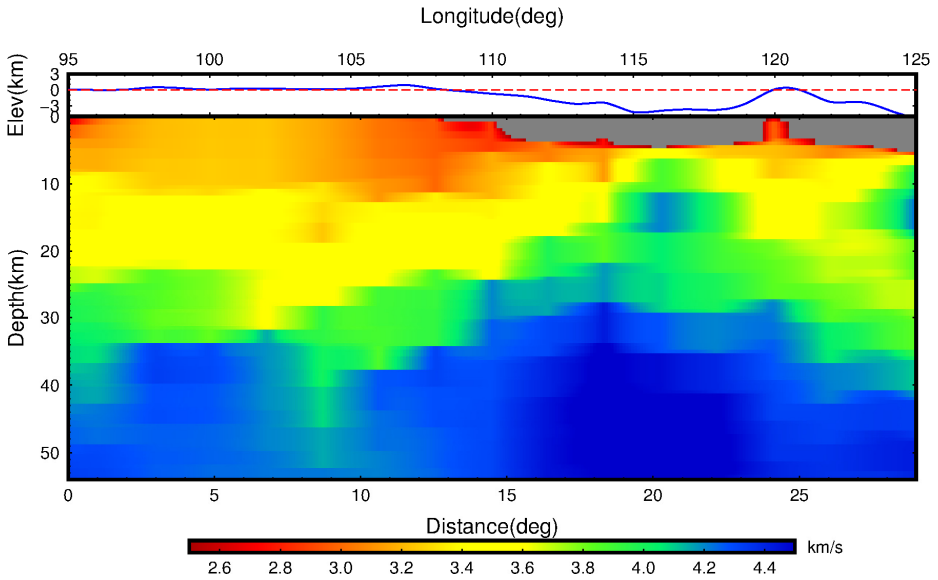
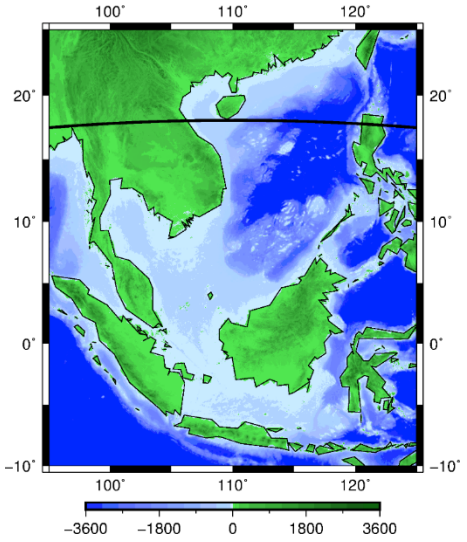
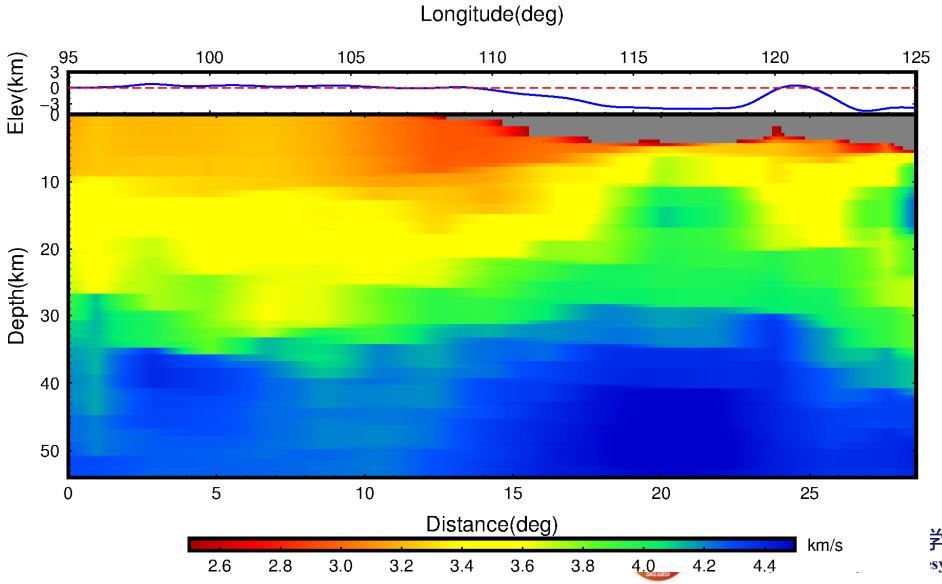
Vertical profiles of velocity structures of SCS









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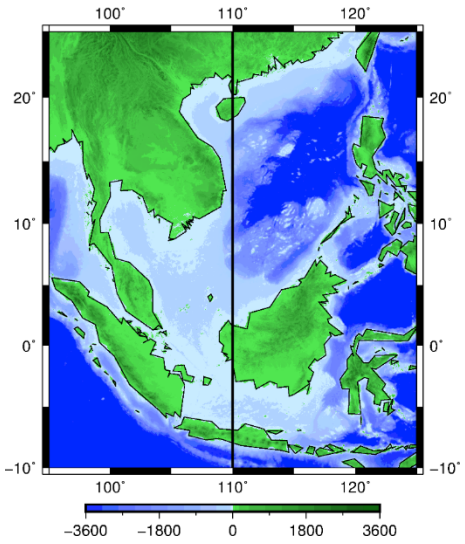
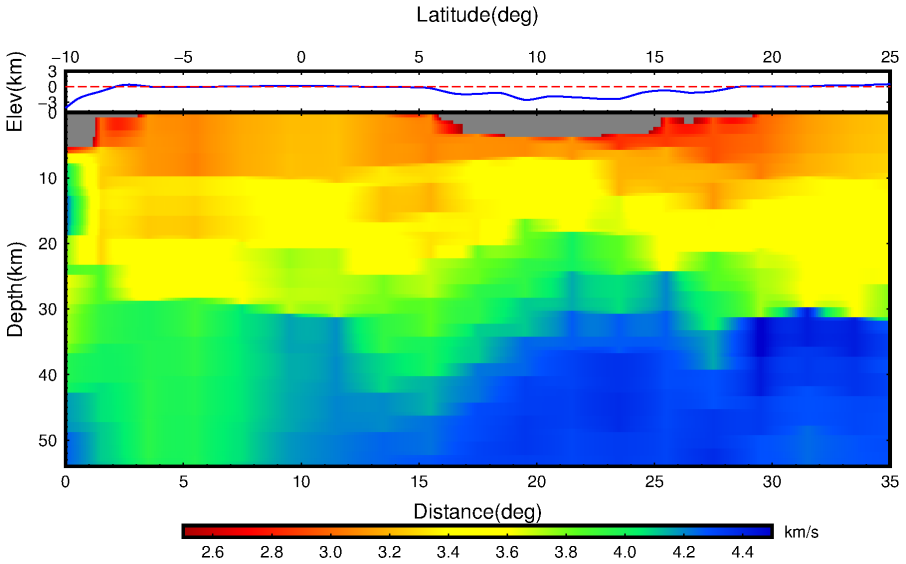
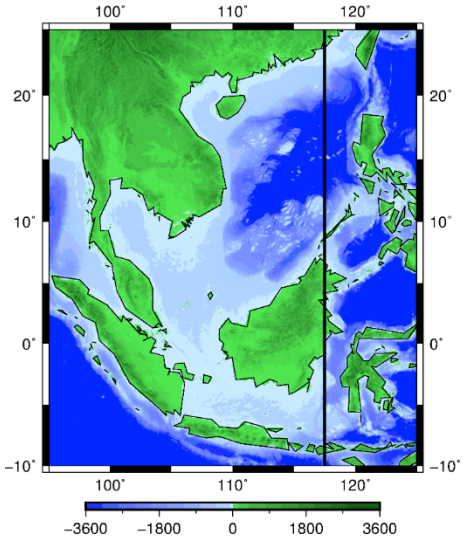
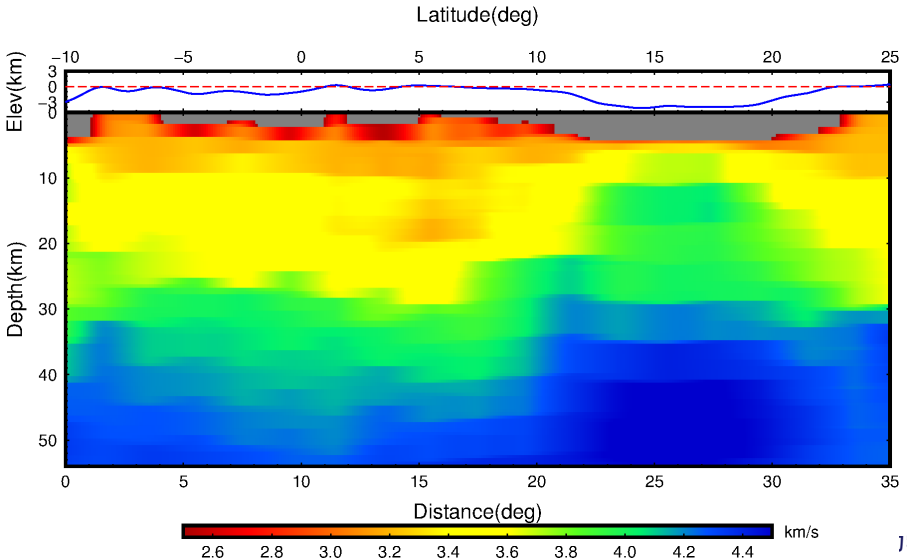
Vertical profiles of velocity structures of SCS



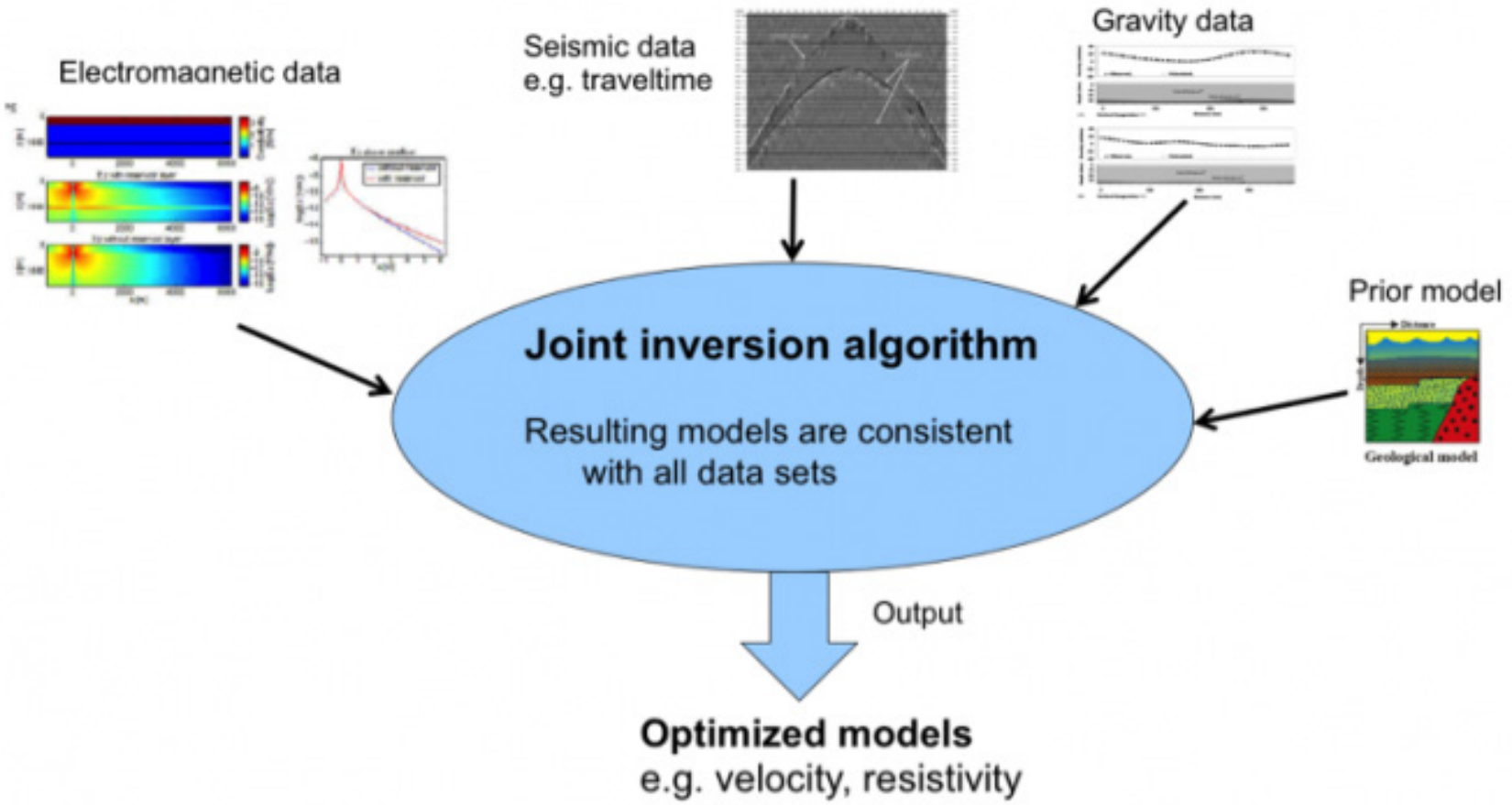






Improve the tomography with joint inversion

Joint inversion of different geophysical datasets is an effective means to reduce the non-uniqueness and improve the reliability of geophysical inversion.



Joint tomography of seismic arrival time and gravity

constraints
- Regularization
- prior/smooth constraints
- weightness

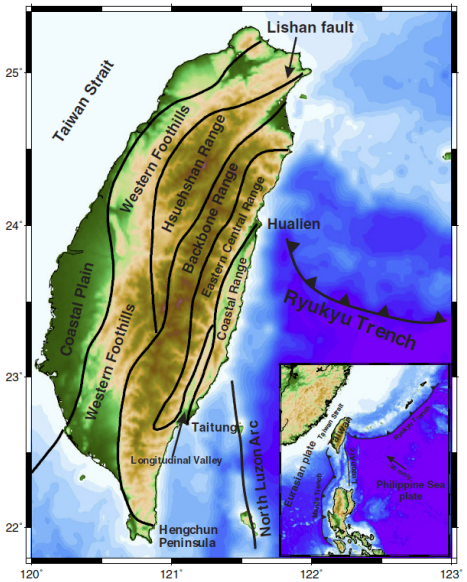
gravity
- $\rho = 989.3 + 289.1 * V_p$ Vp>6.0 km/s
- $\rho = 0.23 * V_p^{0.25}$ Vp<5.5 km/s
- interpolation 6.0km/s>Vp>5.5 km/s

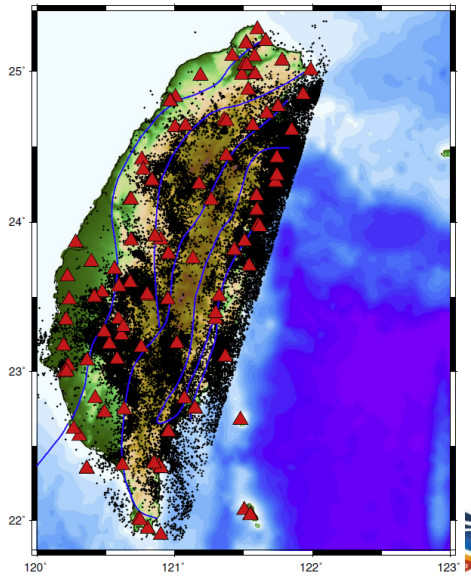
Seismic data

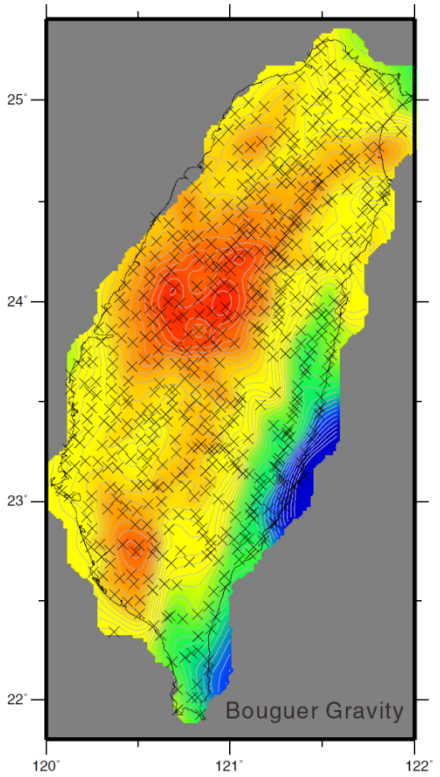
$$\delta t_{ij}^{p} = t_{ij}^{obs} - t_{ij}^{cal} = \sum \frac{\partial t}{\partial S_k^p} \Delta S_k^p + \sum_{l=1}^{4} \frac{\partial t}{\partial q_l^i} \Delta q_l^i$$

$$\delta t_{ij}^{s} = t_{ij}^{obs} - t_{ij}^{cal} = \sum \frac{\partial t}{\partial S_k^s} \Delta S_k^s + \sum_{l=1}^{4} \frac{\partial t}{\partial q_l^i} \Delta q_l^i$$

LSQR







603 Bouguer gravity data

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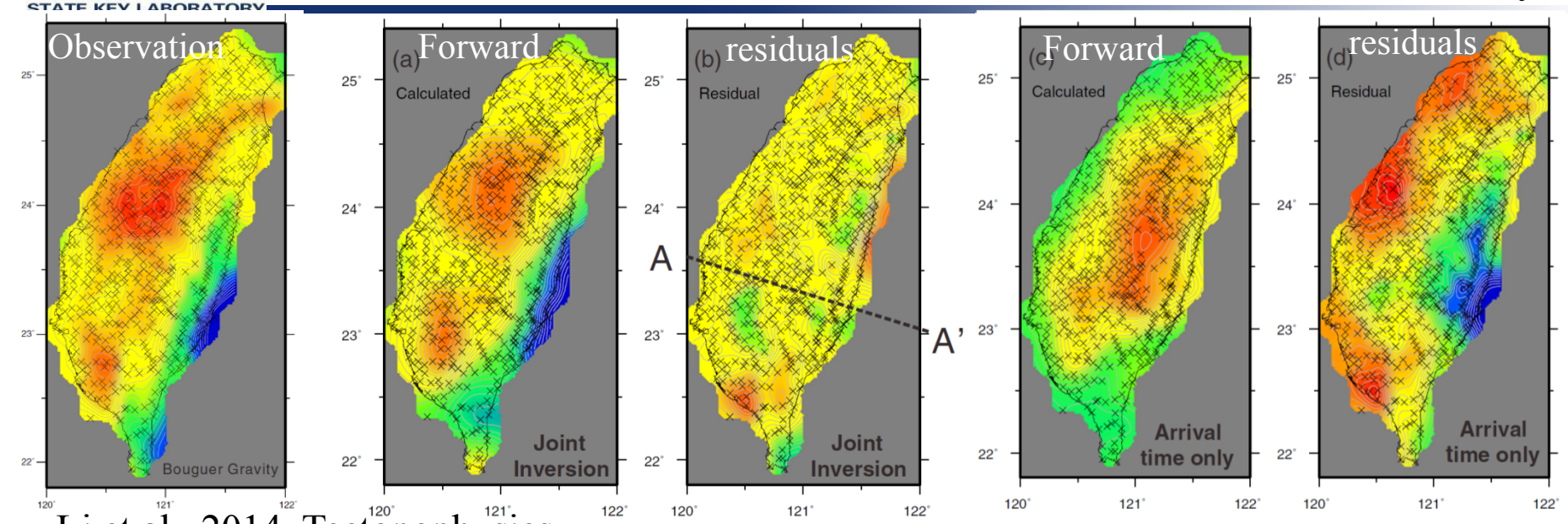
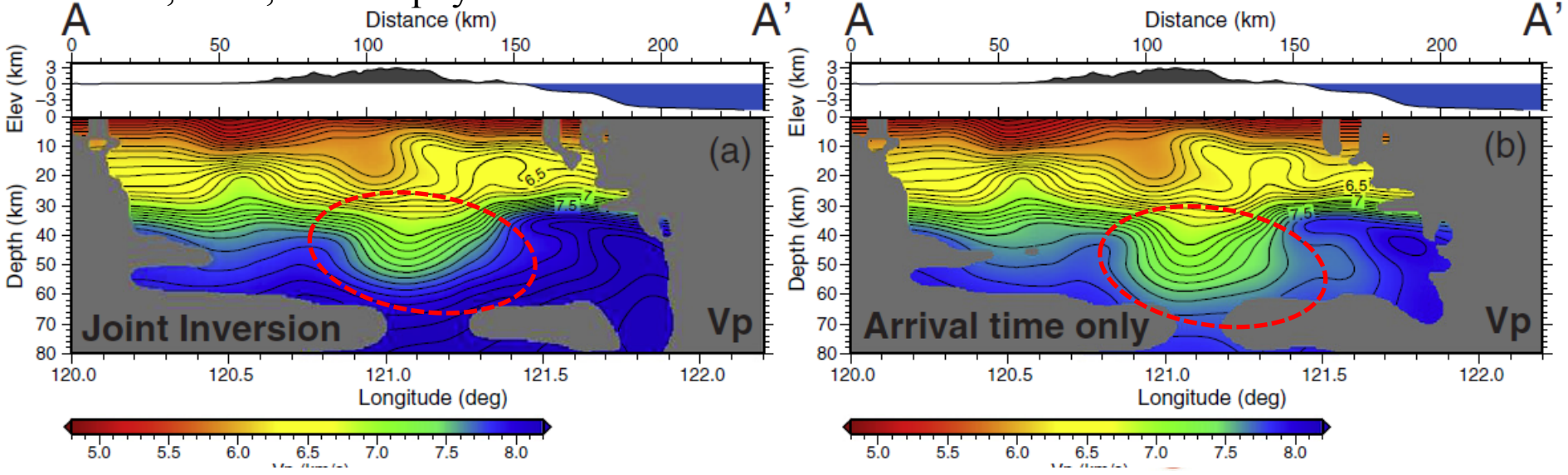
Joint inversion

Seismic inversion only

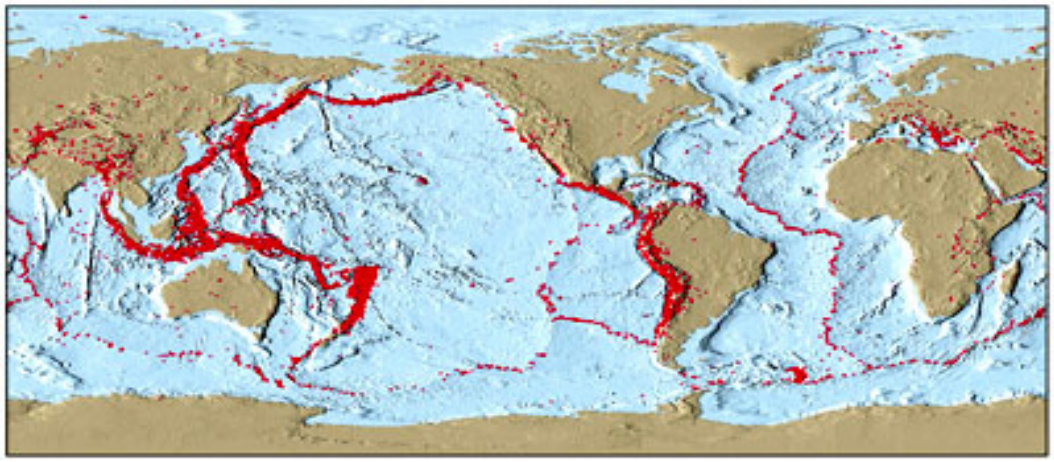


Li et al., 2014, Tectonophysics

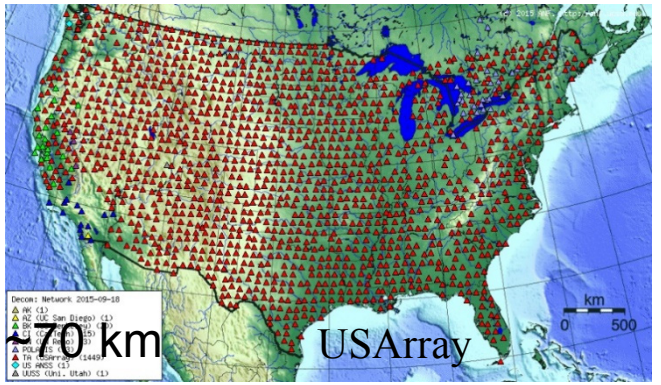


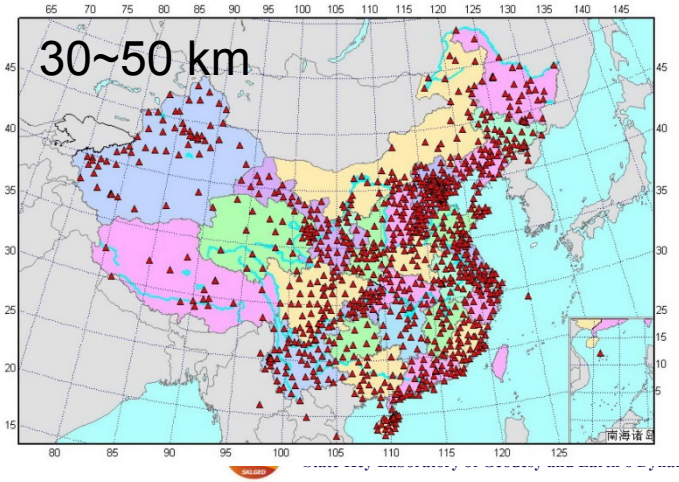
Future works on seismic imaging method

Earthquake distribution are extremely uneven, broadband seismic stations are also very sparse (tens of km), which cannot be easily used to study the detailed 3-D structure for a specified region within a few kilometer depth.



Global earthquake distributions



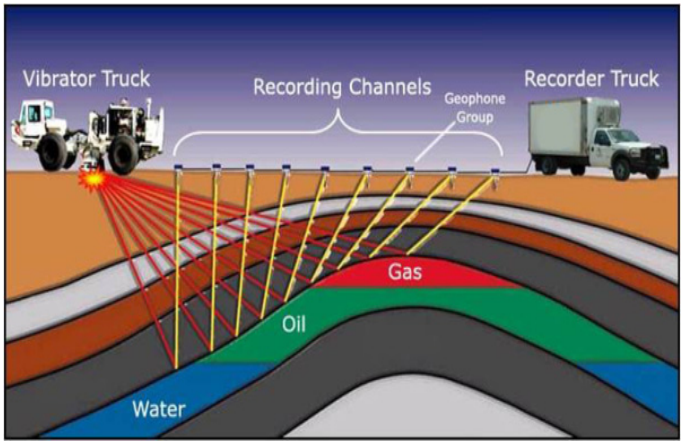


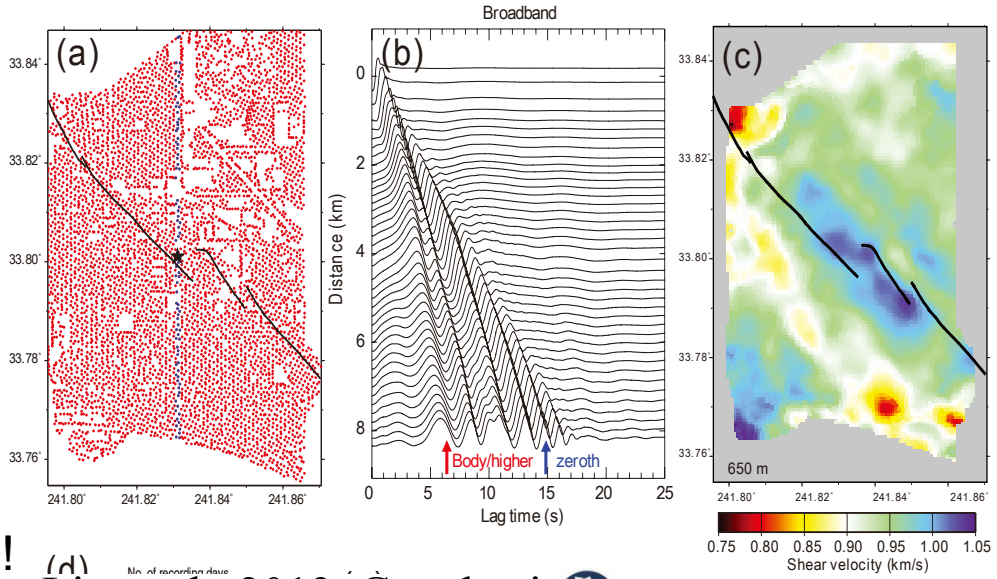
High-resolution 3-D structure for a specific region

High resolution： a few kilometers to hundreds of meters;

Low-cost： Lower than active sources and broadband seismic observation.

Seismic ambient noise tomography by dense array with a large number of low-cost seismometers!





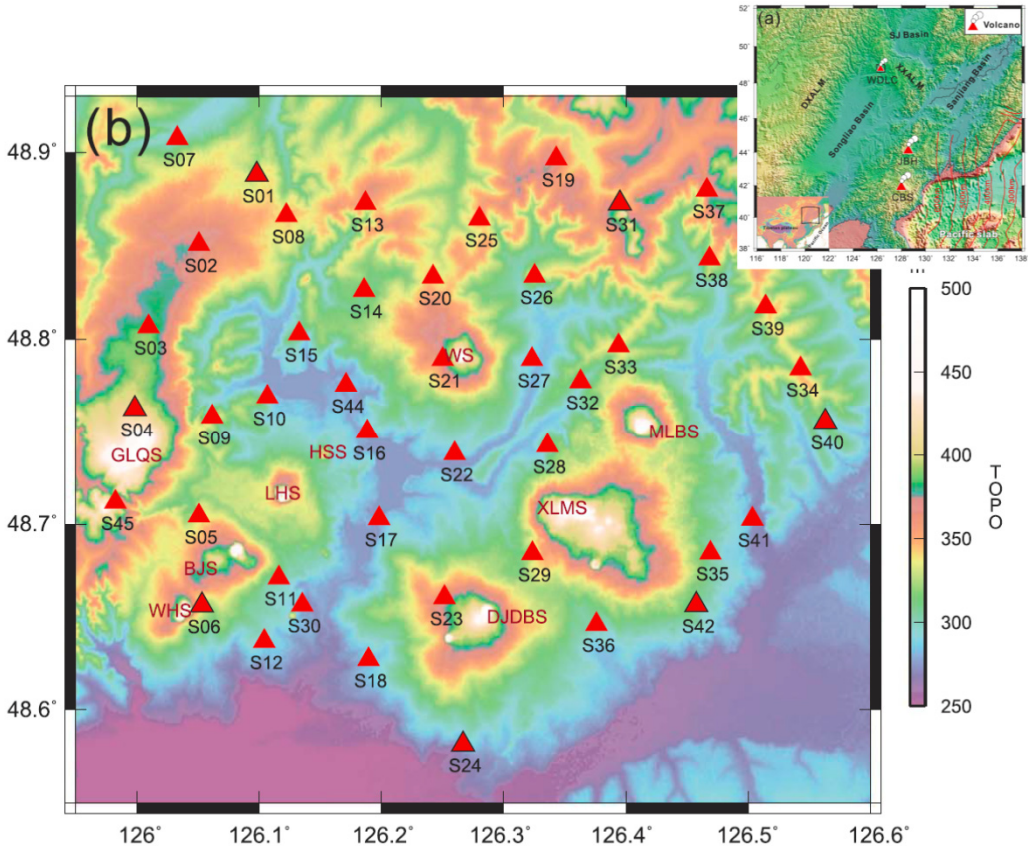
Seismic exploration is too expensive!

Lin et al., 2013, Geophysics

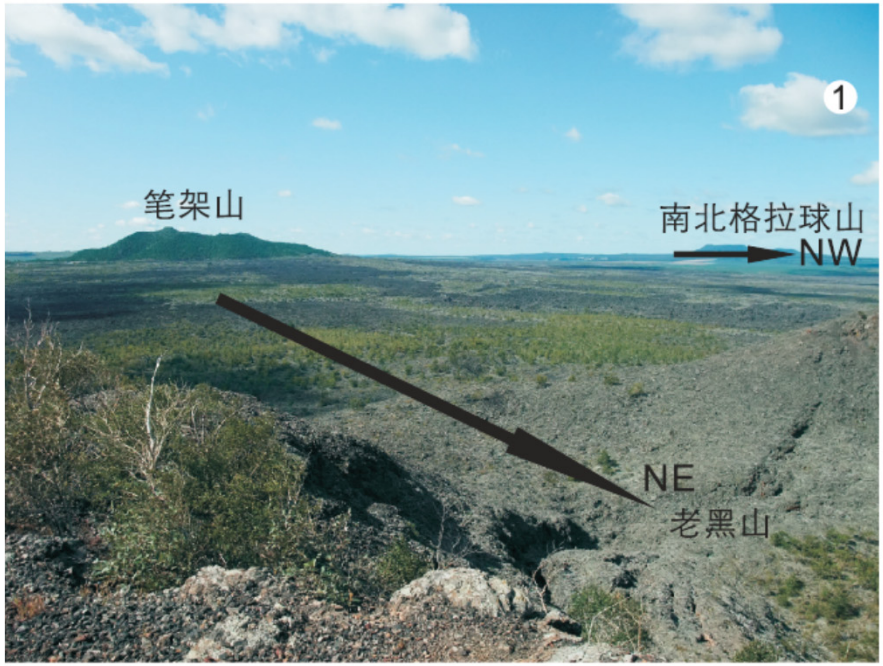
The WDF is ~1800km away from the Pacific plate and 400~600 km to Changbaishan and Jingbohu volcanoes. WDF is an intraplate volcanoes. Peridotite xenoliths yielded the melt equilibration temperatures of 959–1127° C and pressures of 1.27–3.37GPa, suggesting mantle-derived magma from 80 to 100 km depth.

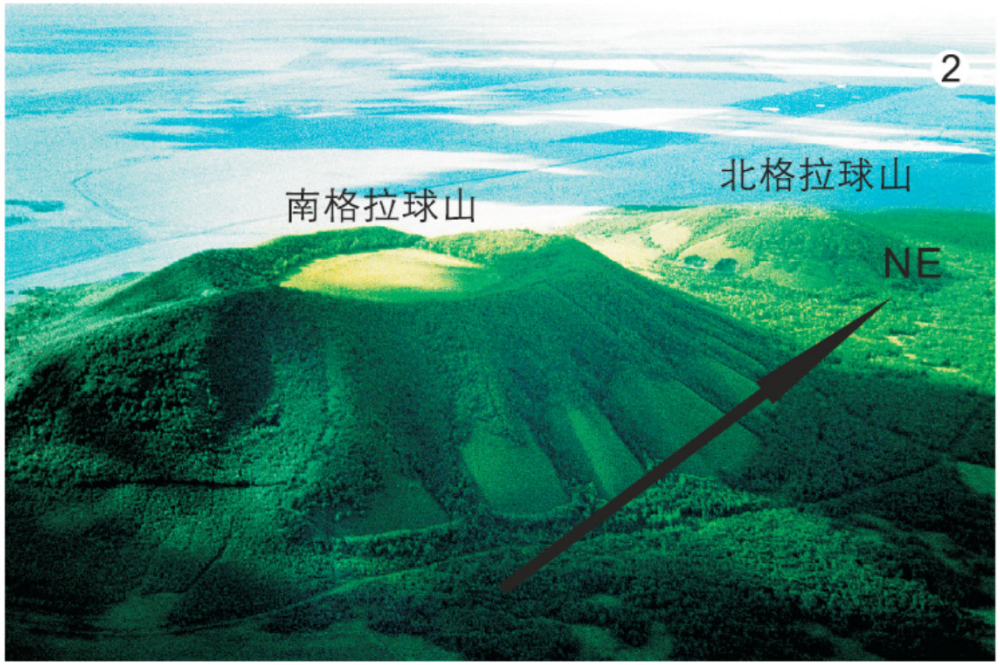
Freq. band: 0.2-100 Hz
low-cost: ~ $1000

seismometers for dense seismic array

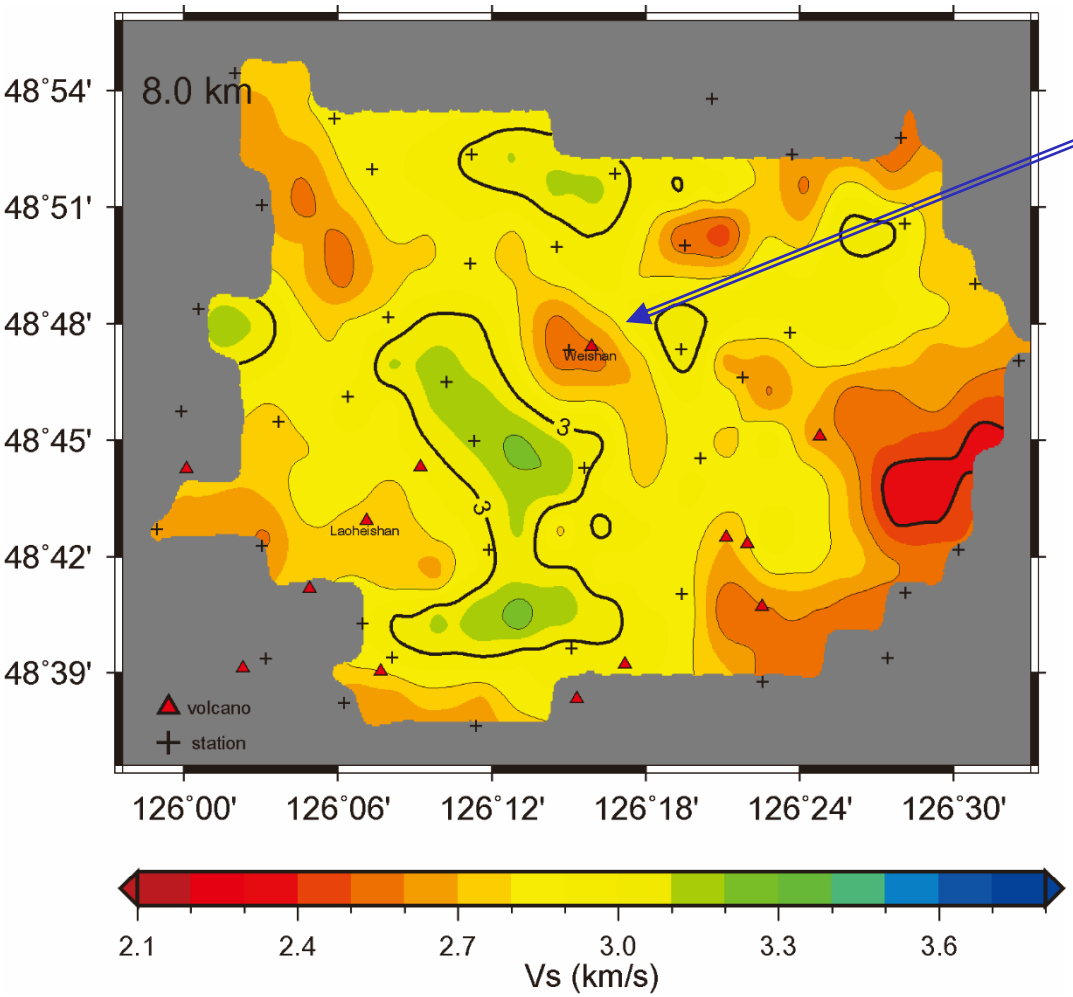


Dense array with 43 seismometers



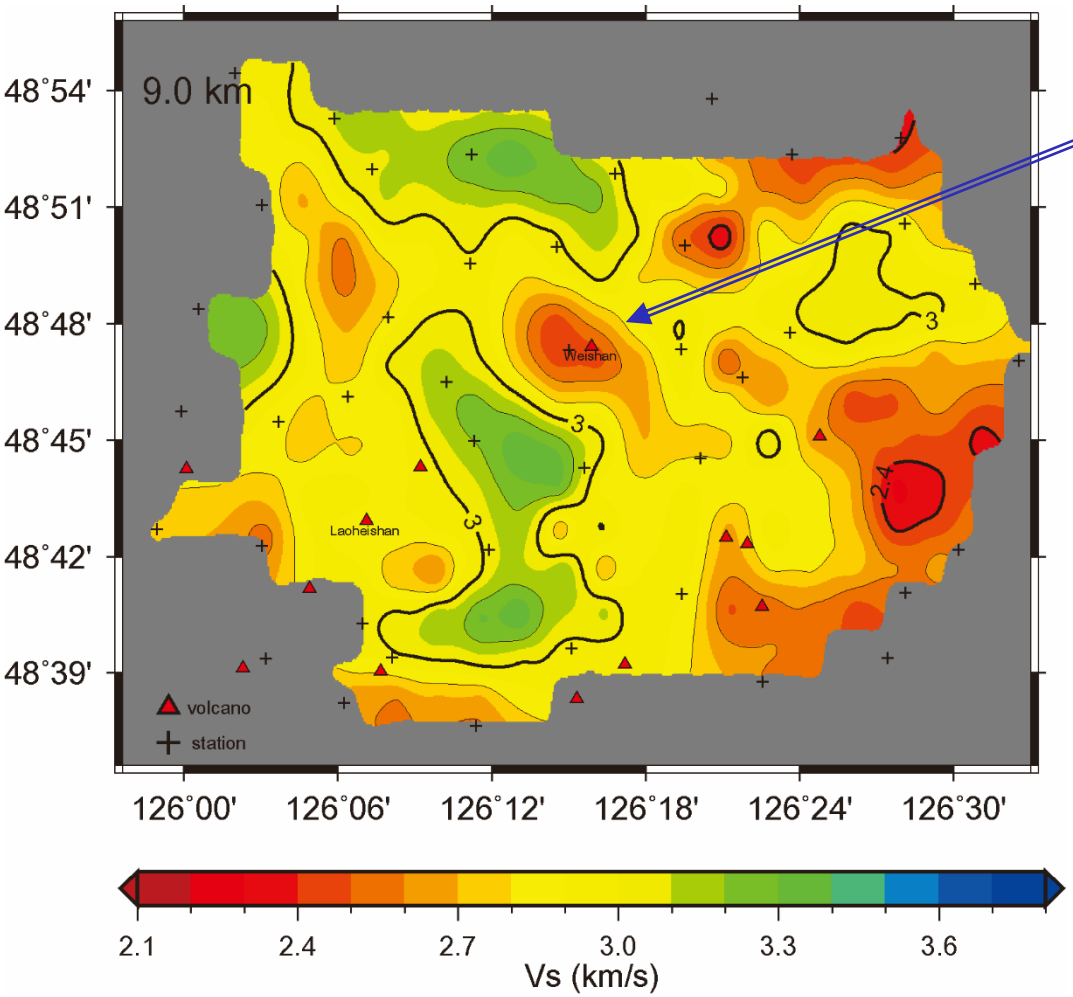


Tomographic images at 8 km depth



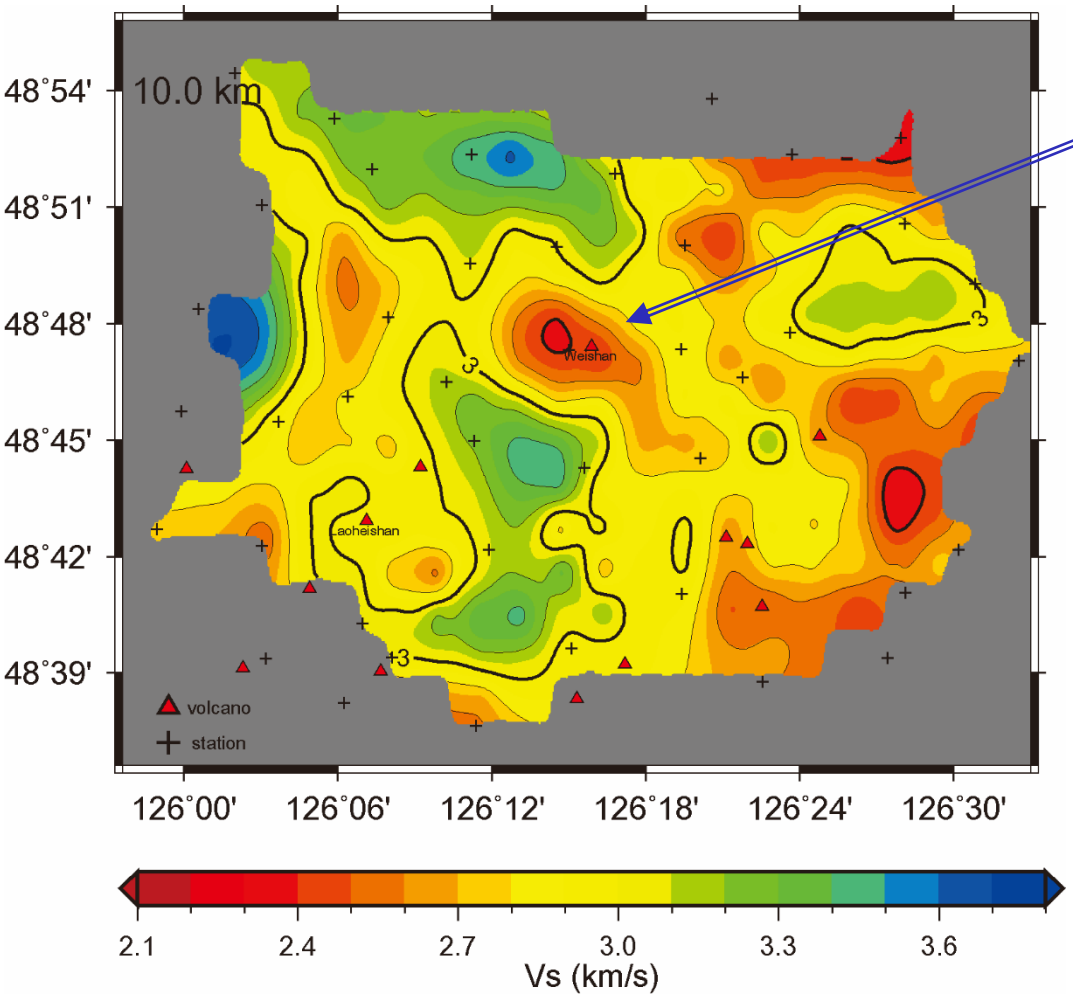
Weishan volcano

Tomographic images at 9 km depth



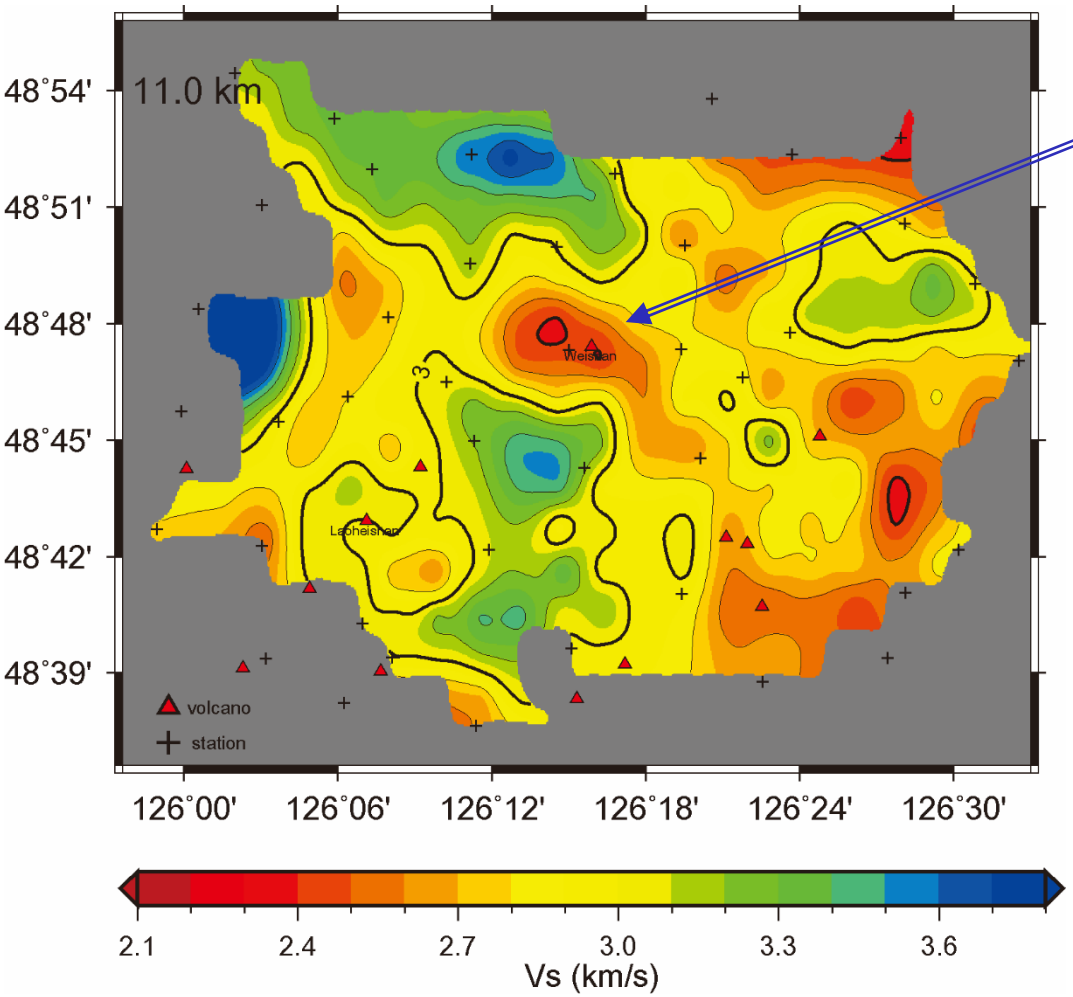
Weishan volcano

Tomographic images at 10 km depth



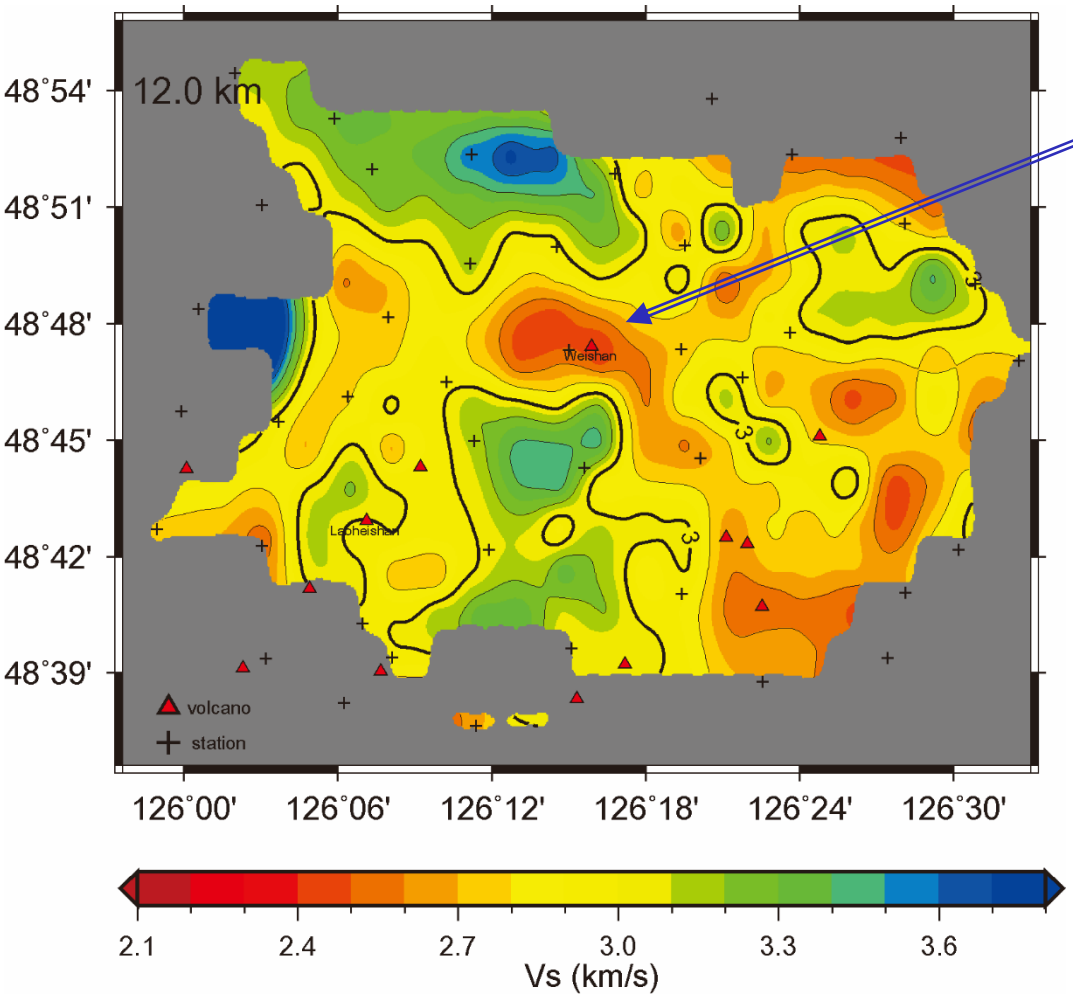
Weishan volcano

Tomographic images at 11 km depth



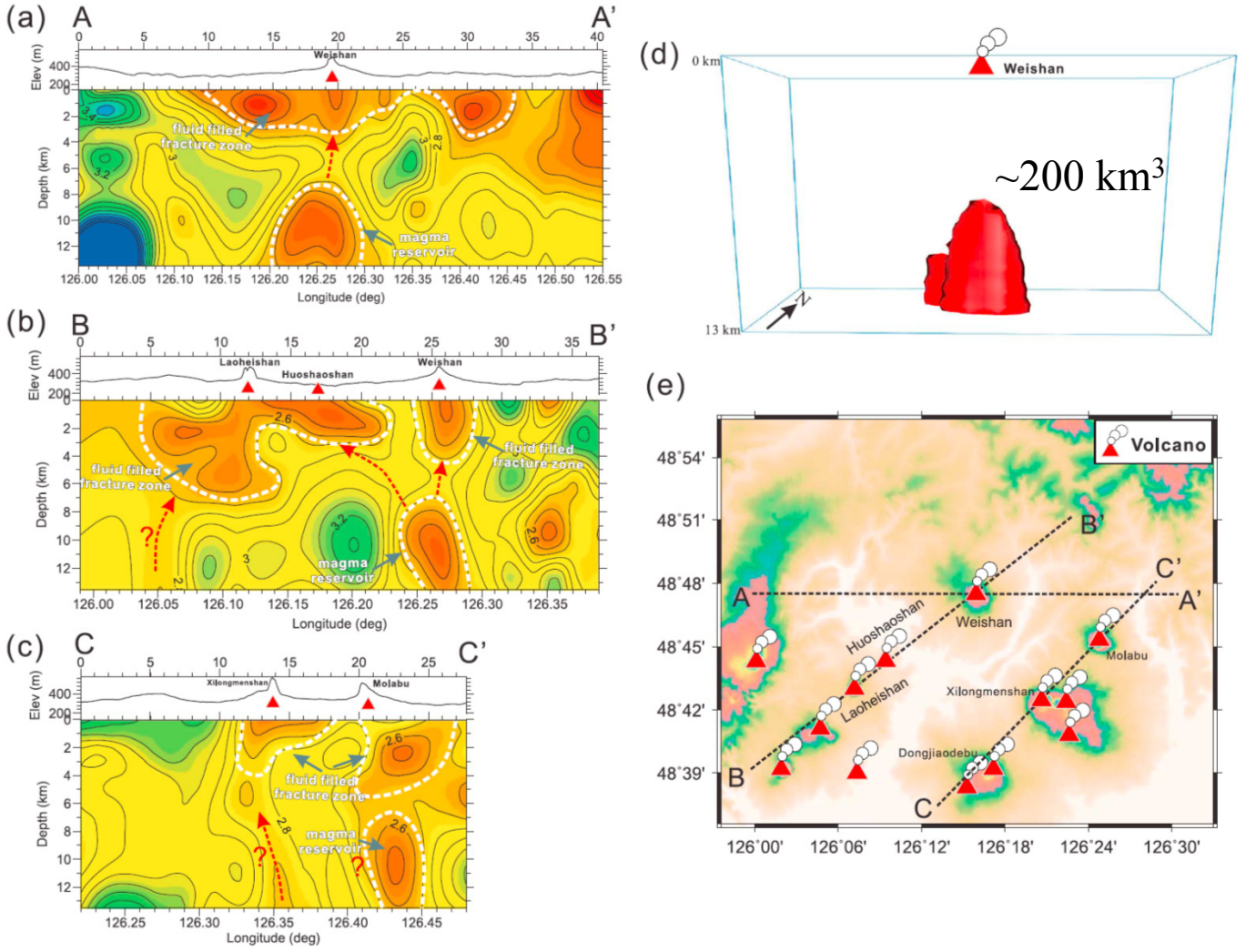
Weishan volcano

Tomographic images at 12 km depth



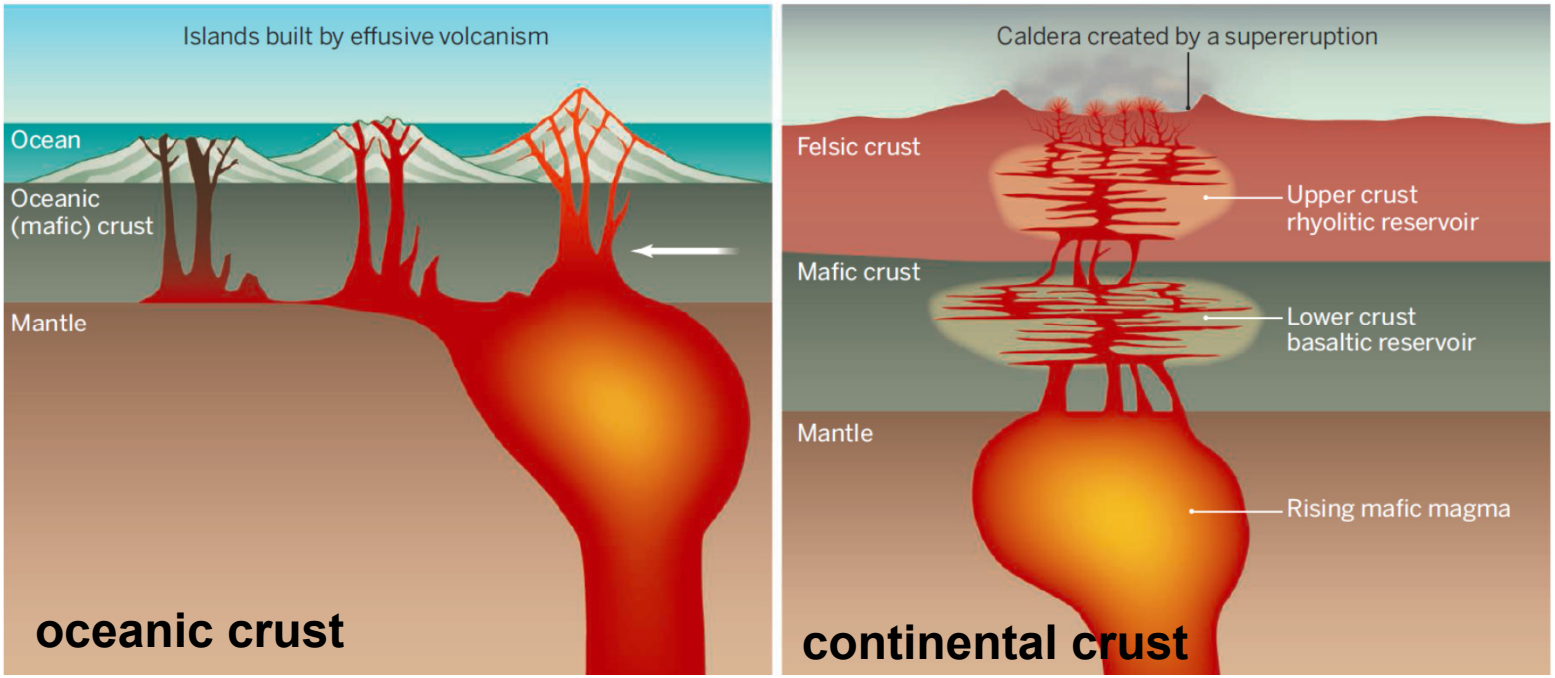
Weishan volcano

Magma chamber beneath Weishan volcano cone



Li et al., 2016, GRL

Mafic magmatic fluids remain buoyant within the oceanic crust and traverse it almost without obstacles. Within the continental crust, basaltic magmas cannot easily ascend through the low-density felsic rocks and are accumulated in sill complexes at depth, which **leads to a formation of intermediate magma reservoirs**.

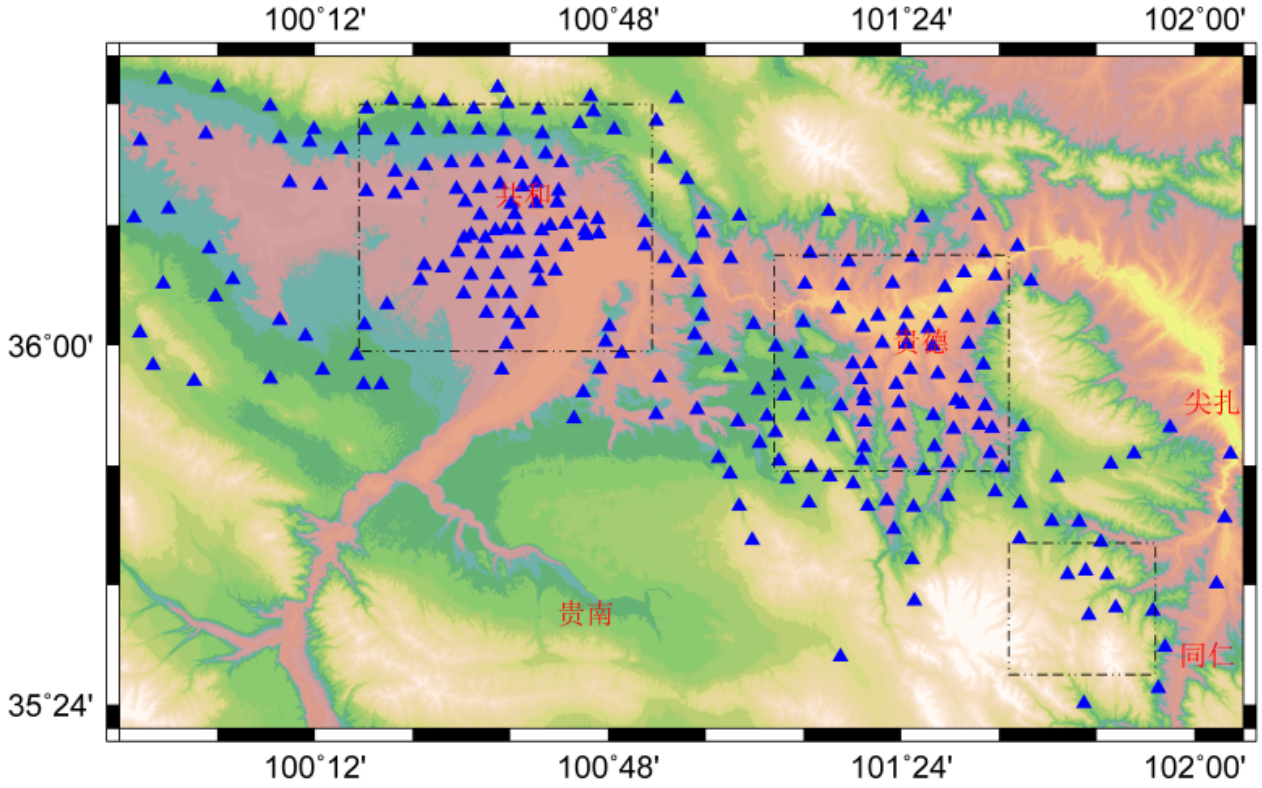


Shapiro & Koulakov, 2015, Science

Dense array observation in Qinghai province

2016.8~12, ~250 seismometers, 3~10 km intervals

For hot-dry rock resource investigation



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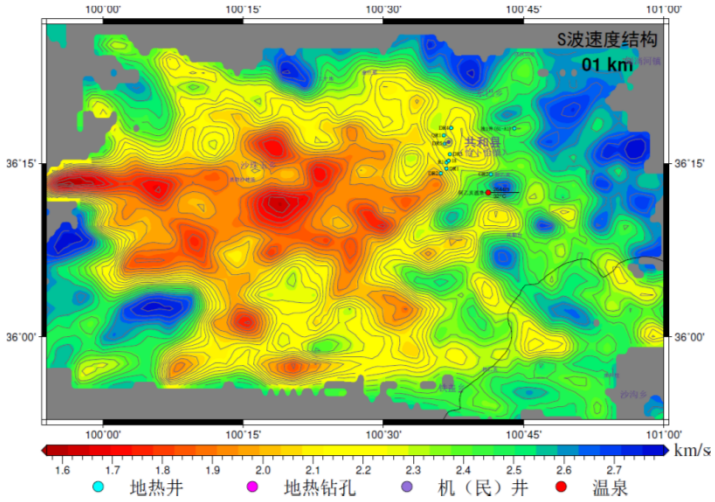
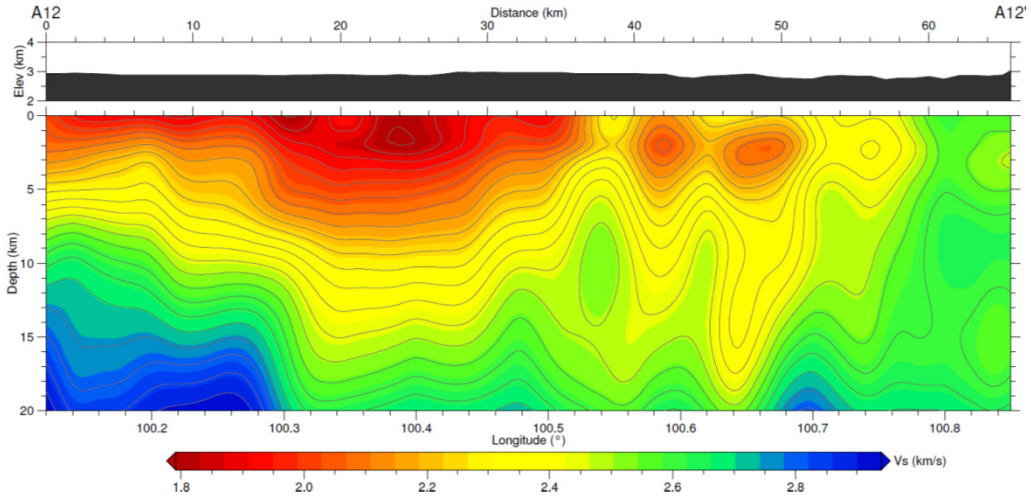
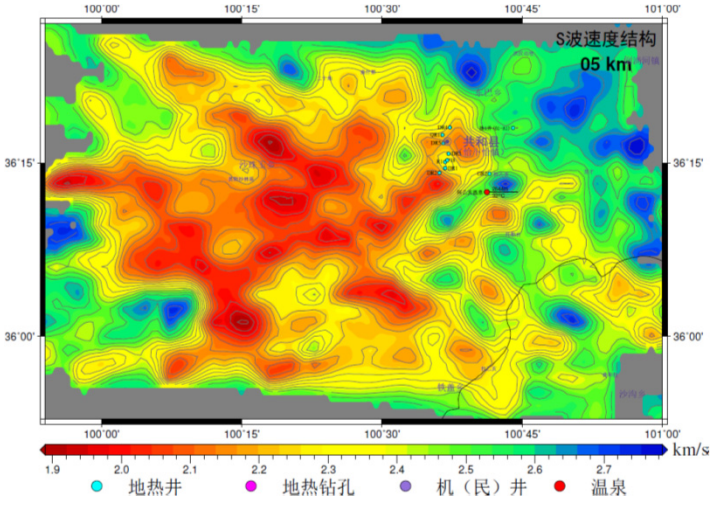
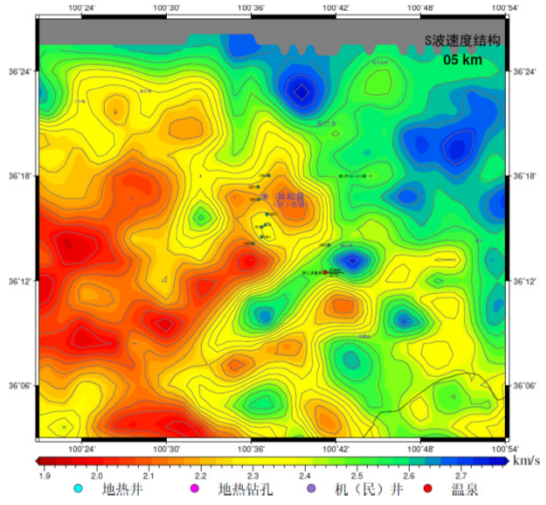
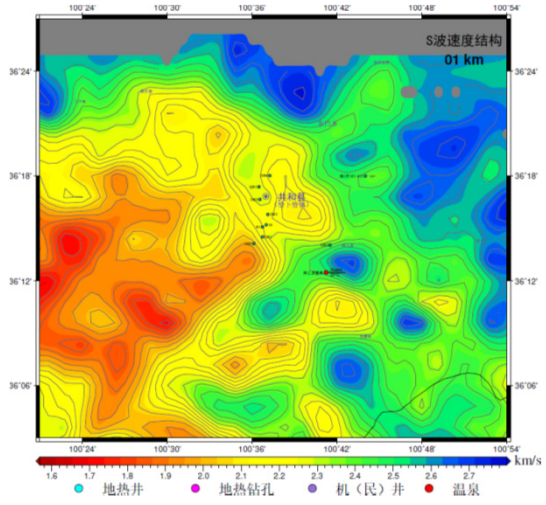
Seismic imaging for Gonghe region at 1~20 km depth



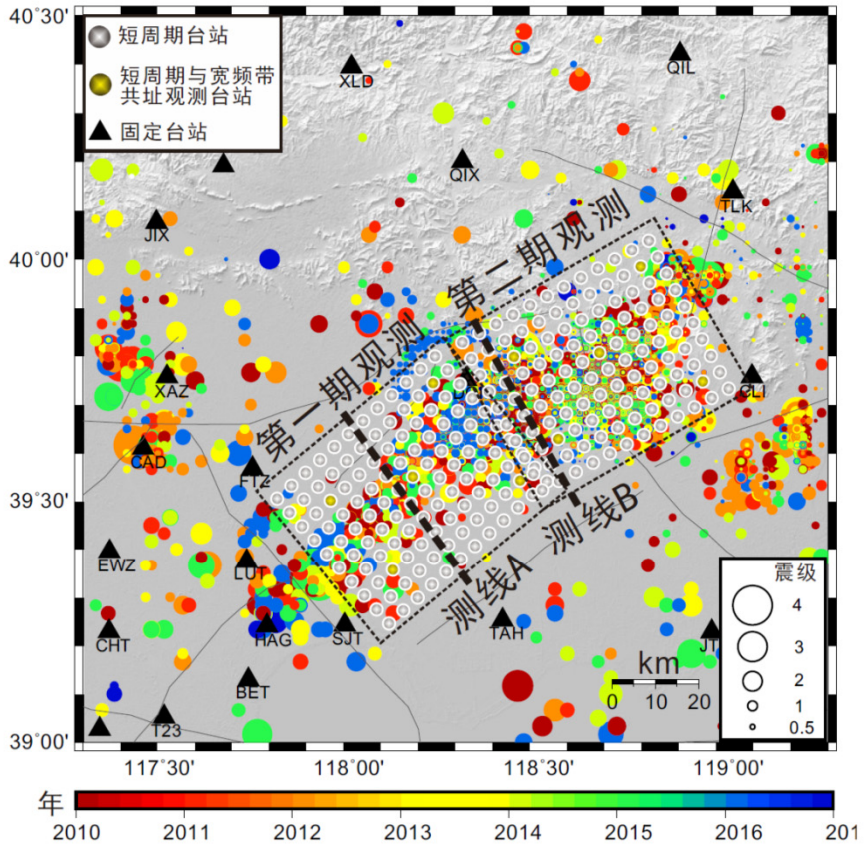


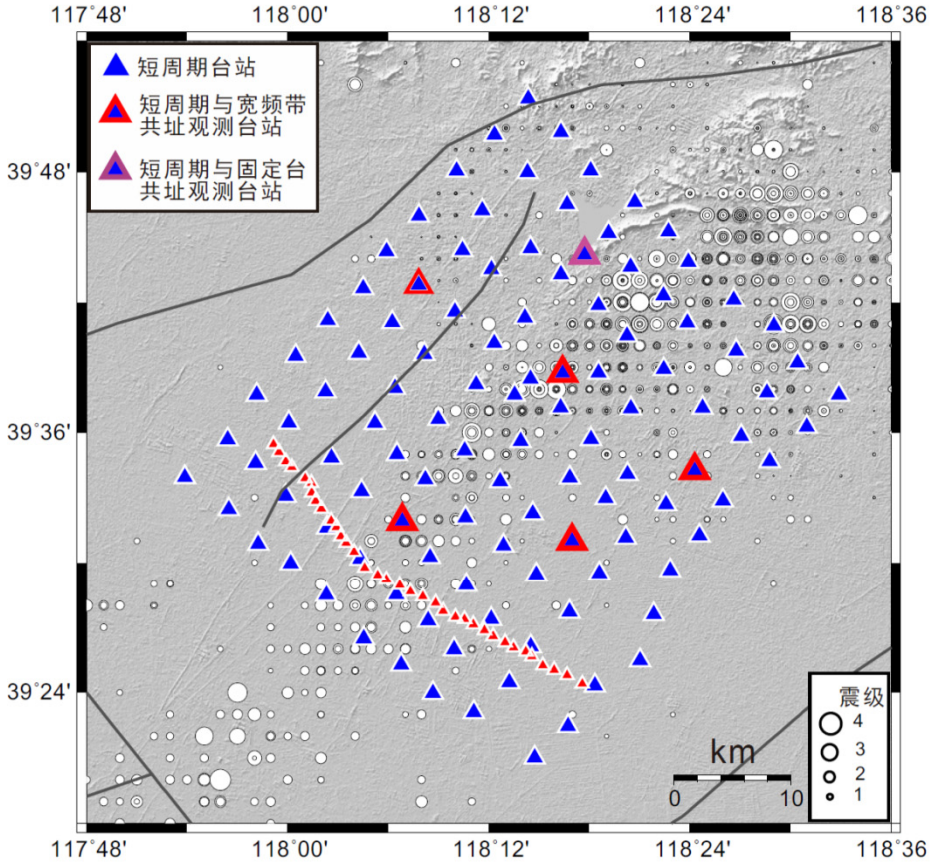




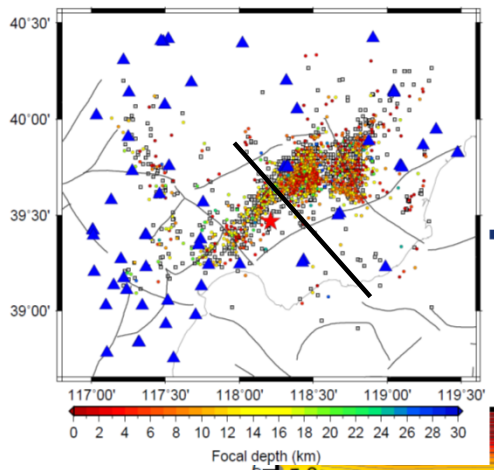


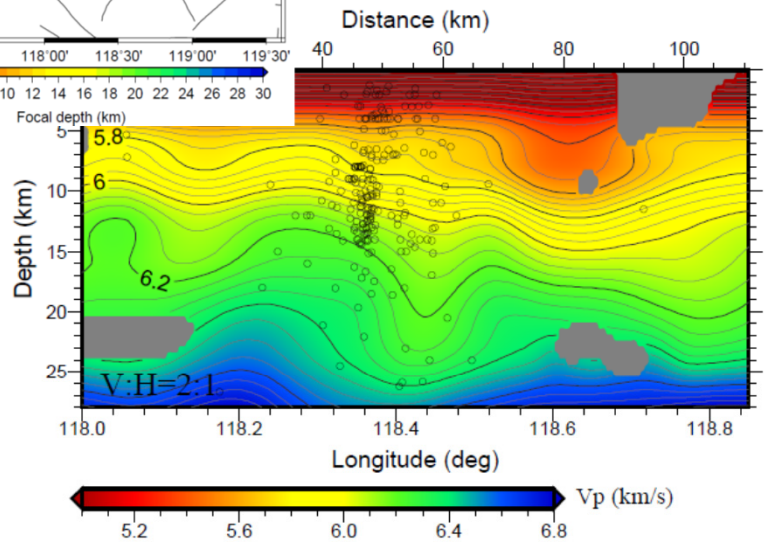
Dense seismic array and passive sources in Tangshan *M*7.8 earthquake region for detailed 3-D structures. Field work has finished during Jan.~ Mar., 2017.

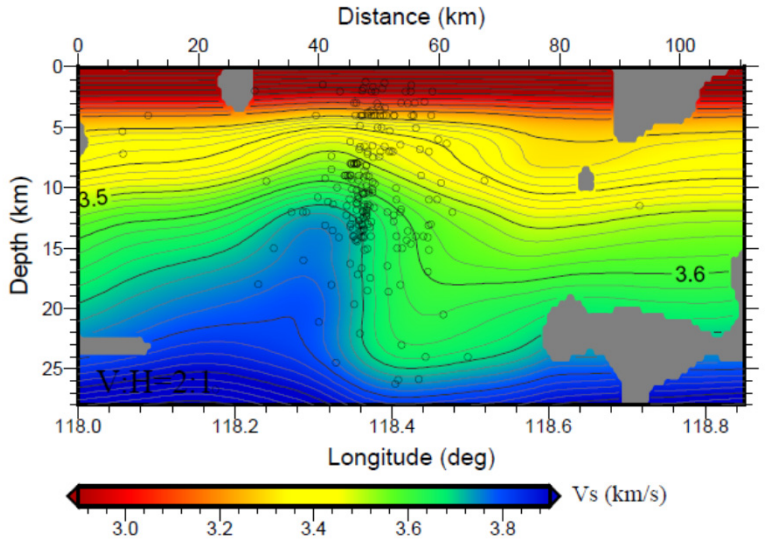


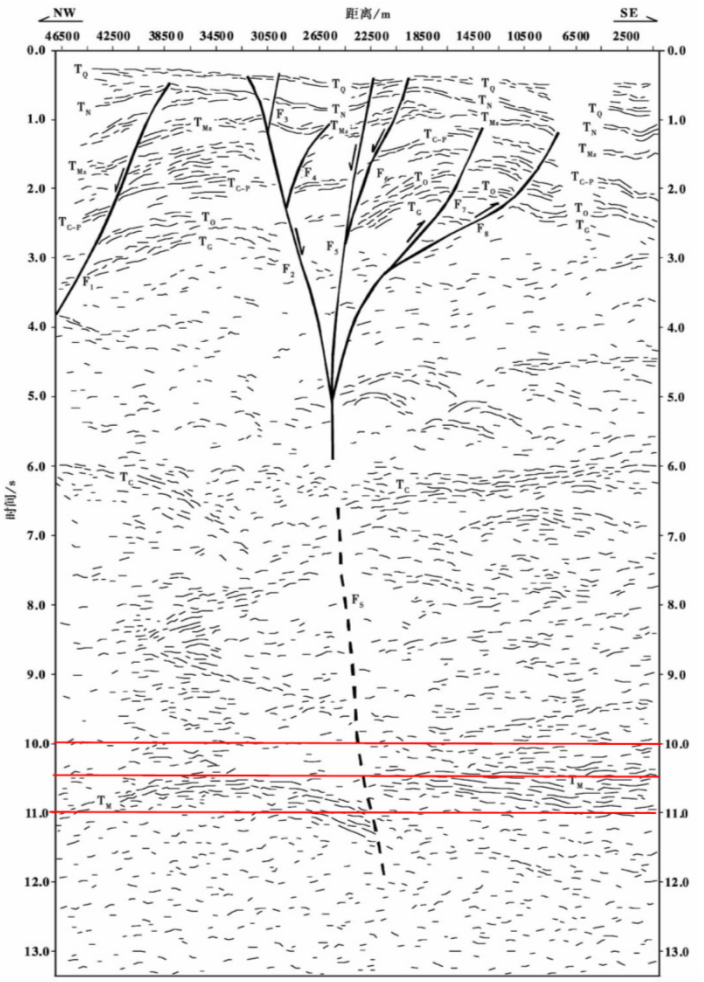


3-D tomography & deep seismic reflection profile



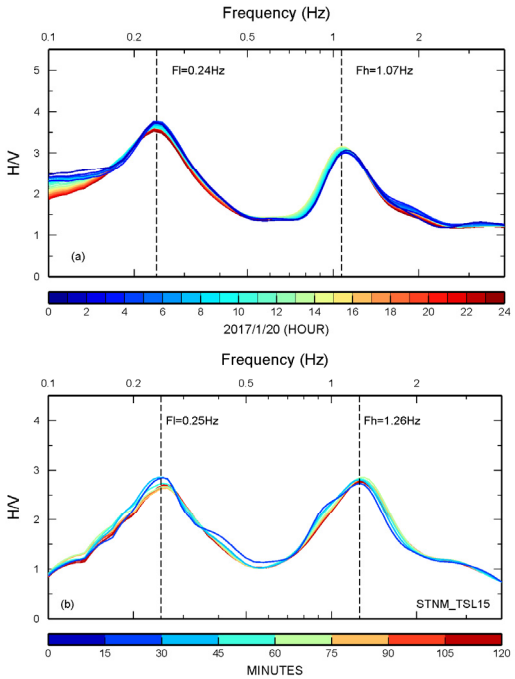




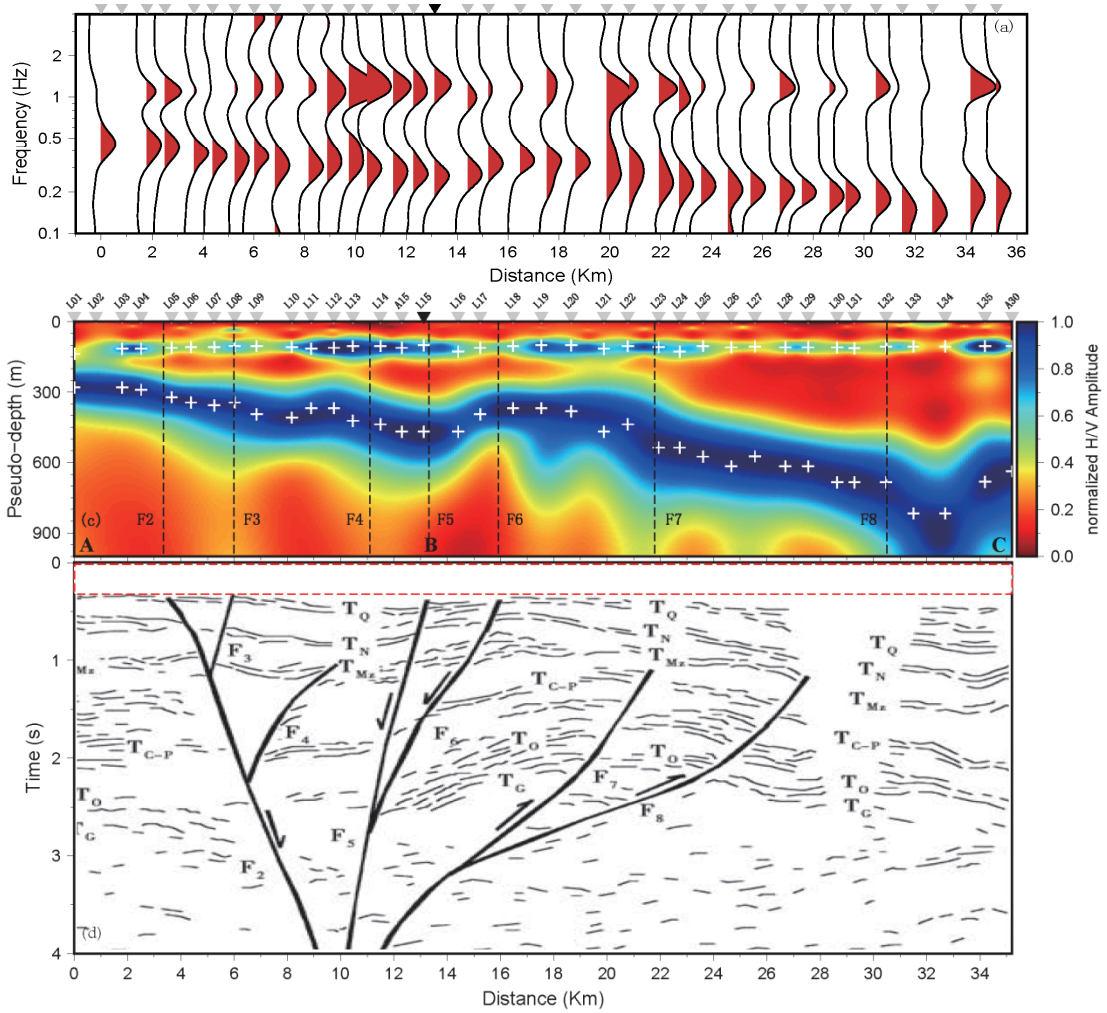


Liu et al, 2011

H/V profile and Tangshan Fault detection

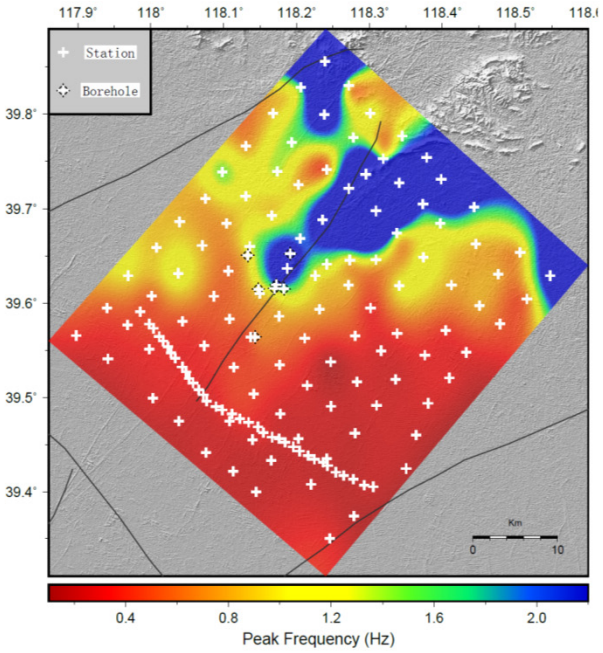


Bao & Li, 2017, in preparation

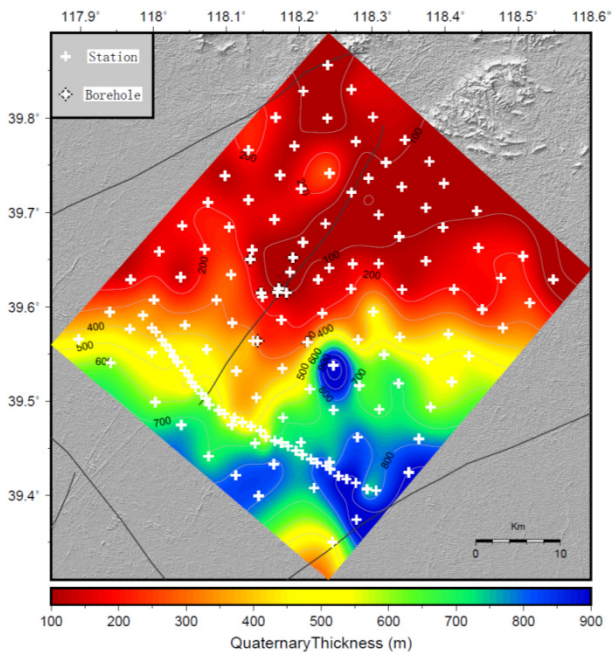


Liu et al., 2011

H/V peak frequency f0



Thickness corresponding to f0



Quaternary sediment thickness

You et al., 2002

Bao & Li, 2017, in preparation

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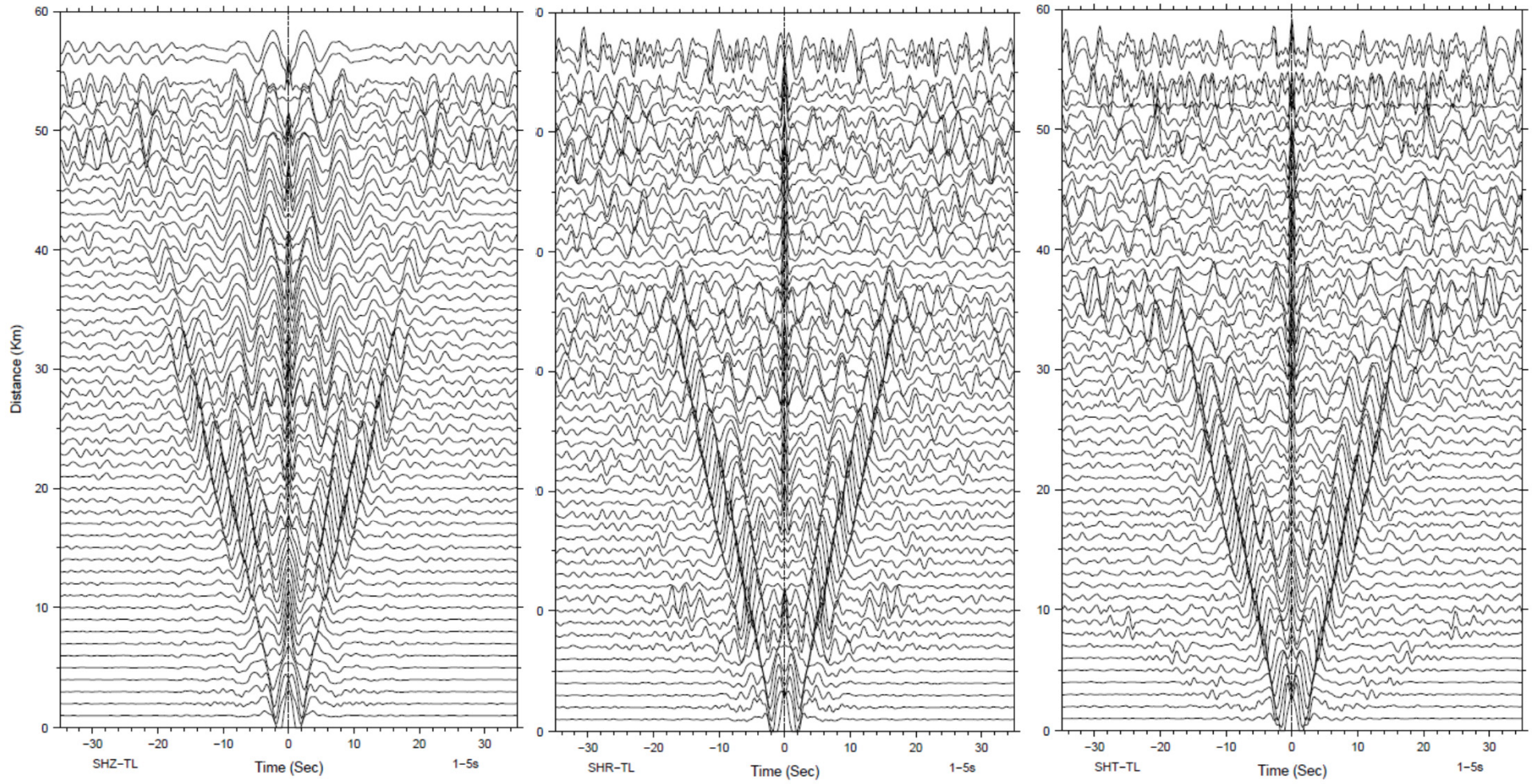
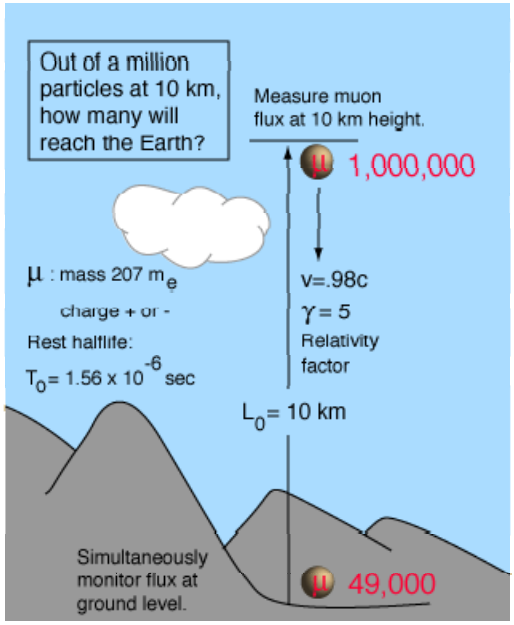
Noise cross-correlation functions from Z/R/T components

Z R T



3-D density structure imaging with cosmic-ray muon



Distance: $L_0 = 10^4$ meters

Time: $T = \frac{2000\ m}{(0.98)(3 \times 10^8\ m/s)}$

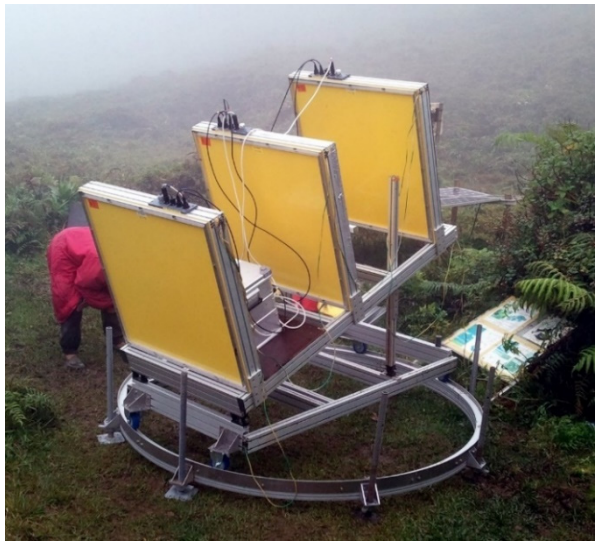
$T = 6.8 \times 10^{-6}$ s = 4.36 halflives

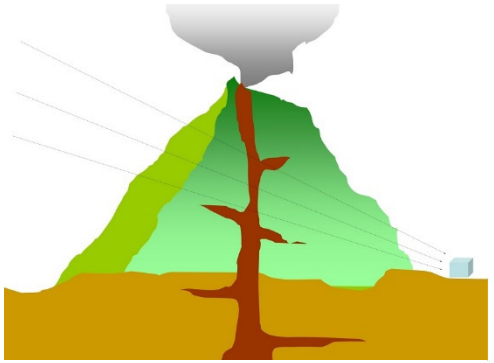
Survival rate:

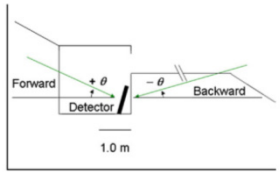
$\frac{I}{I_0} = 2^{-4.36} = 0.049$

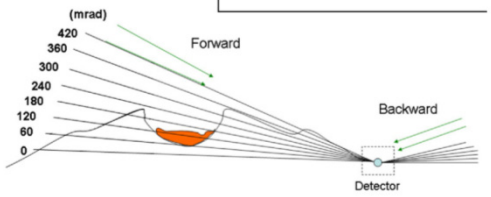
Or about 49,000 out of a million.

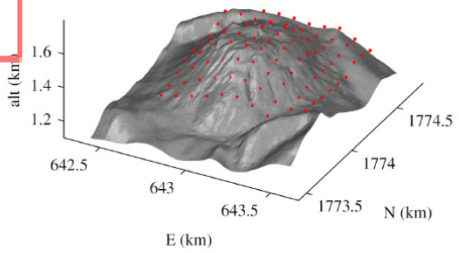
The muon sees distance as length-contracted so that $L = L_0/\gamma = 0.2 L_0 = 2$ km.



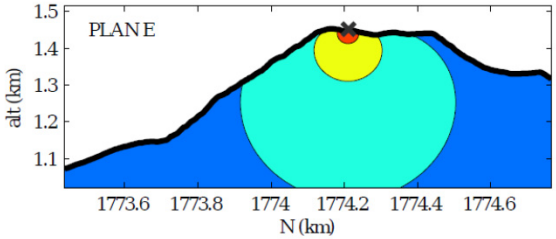




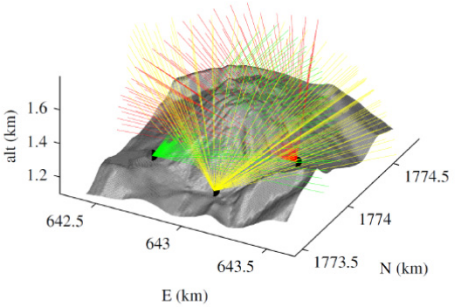




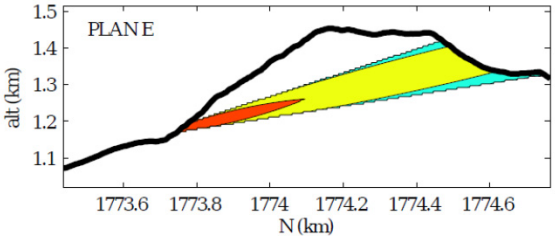
(1) gravimetry coverage



(1) gravimetry acquisition kernel, $\mathcal{G}$



(2) tomography coverage



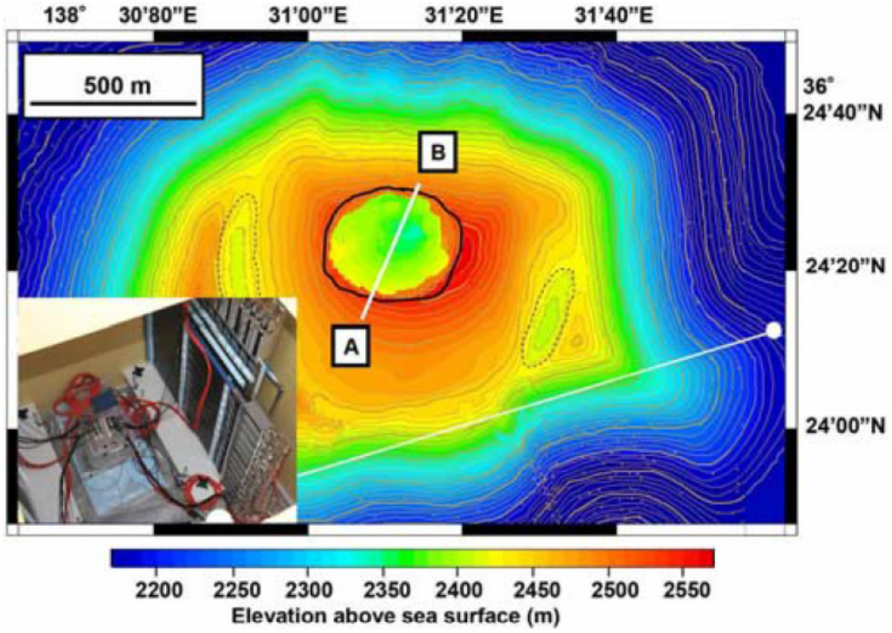
(2) tomography acquisition kernel, $\mathcal{M}$

Jourde et al., 2015

GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L17302, doi:10.1029/2009GL039448, 2009

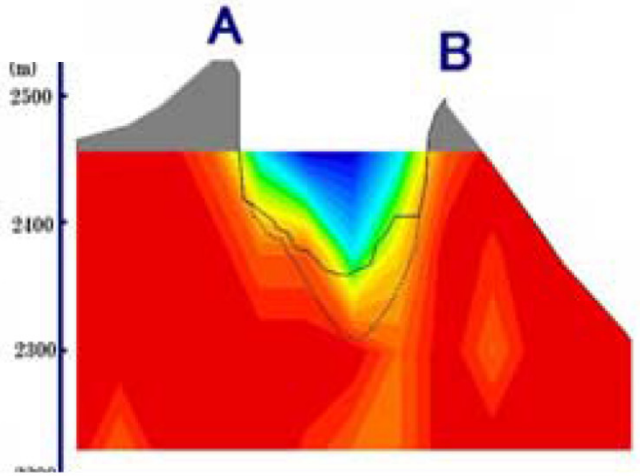
Detecting a mass change inside a volcano by cosmic-ray muon radiography (muography): First results from measurements at Asama volcano, Japan

Hiroyuki K. M. Tanaka,[1,2] Tomihisa Uchida,[3] Manobu Tanaka,[3] Minoru Takeo,[1] Jun Oikawa,[1] Takao Ohminato,[1] Yosuke Aoki,[1] Etsuro Koyama,[1] and Hiroshi Tsuji[1]

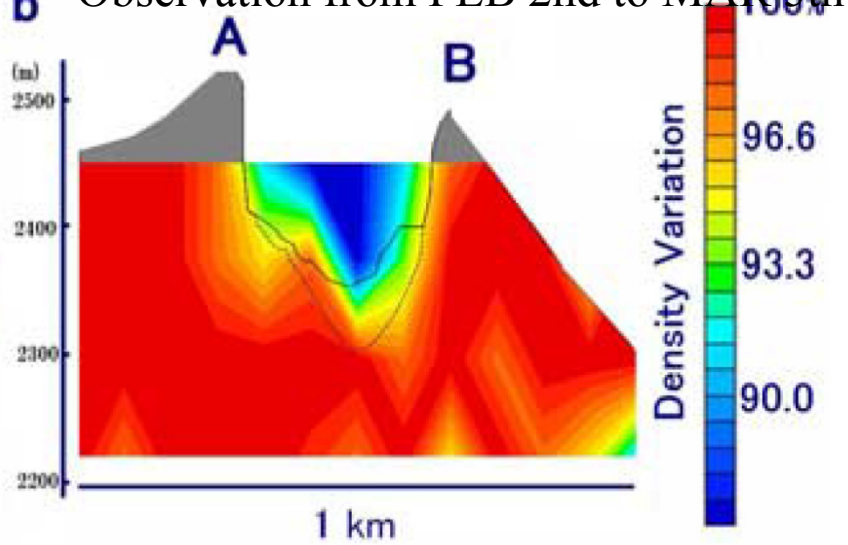


Average density distribution projected on the cross sectional plane that is parallel to the detector plane and that includes the crater floor of Asama.

Observation from JAN 6th to FEB 1st



Observation from FEB 2nd to MAR 5th



AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2017GL074285

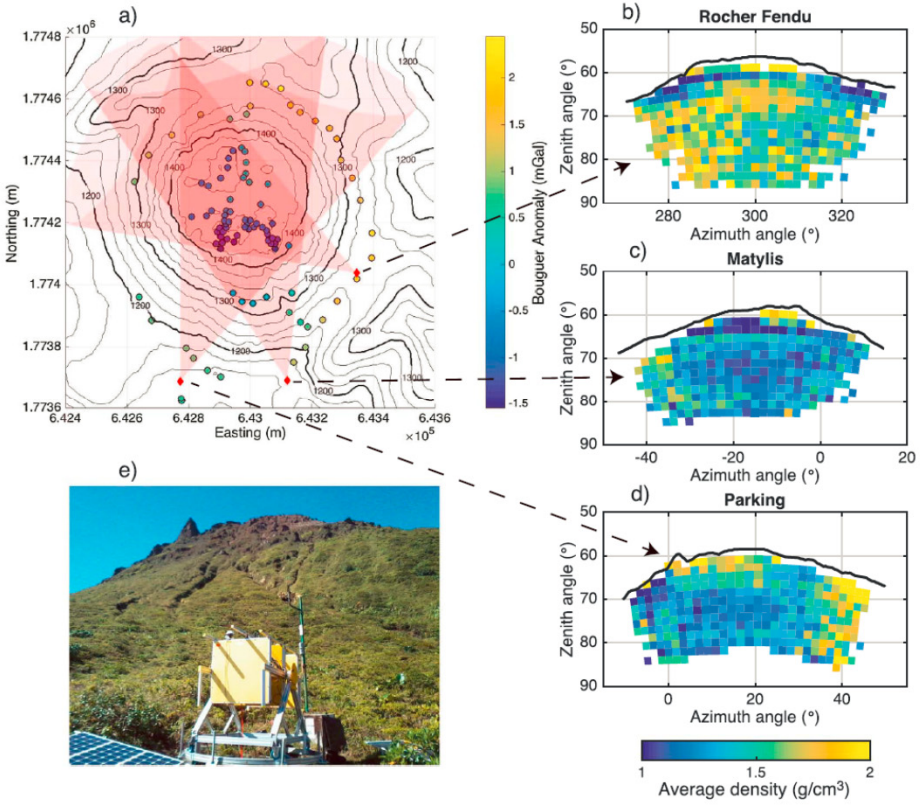
Three-dimensional density structure of La Soufrière de Guadeloupe lava dome from simultaneous muon radiographies and gravity data

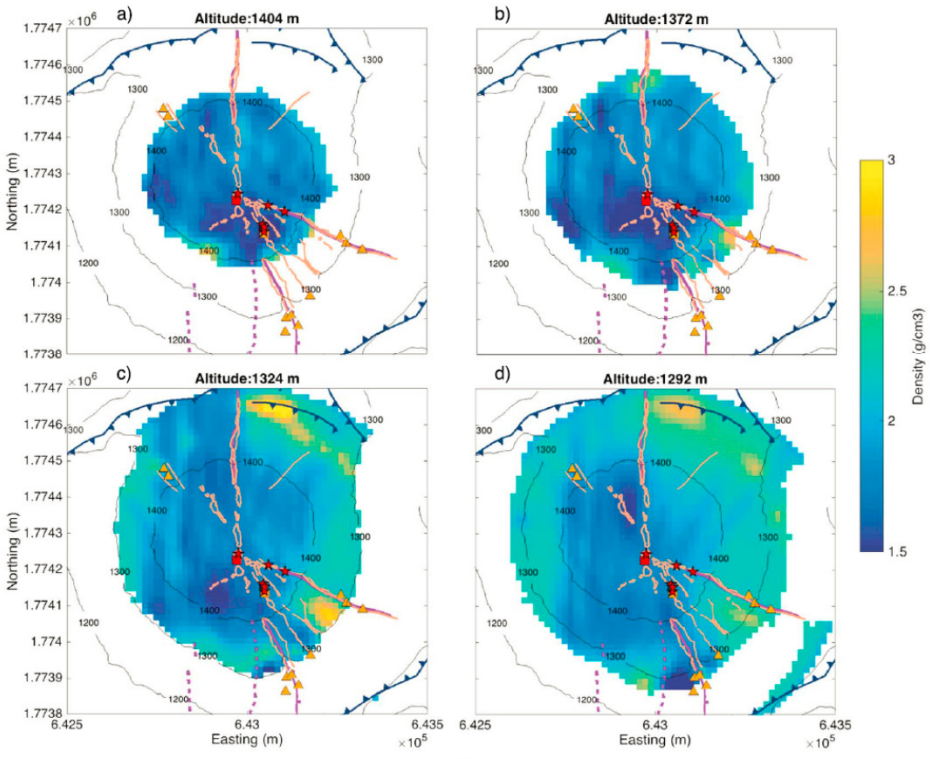
Key Points:
- We simultaneously image the La Soufrière de Guadeloupe lava dome with three muon telescopes aiming at the volcano from different locations

M. Rosas-Carbajal[1], Kevin Jourde[2], Jacques Marteau[3], Sébastien Deroussi[4], Jean-Christophe Komorowski[1], and Dominique Gibert[5]

muon telescope and Muon radiographies obtained with the three telescopes.

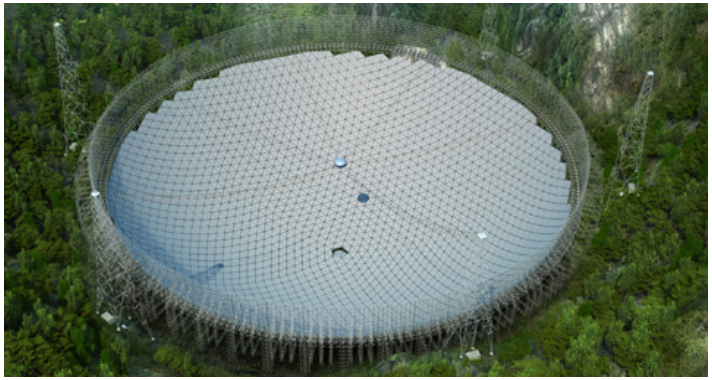
Horizontal slices of the 3-D density model obtained from the joint inversion of field muon and gravity data.



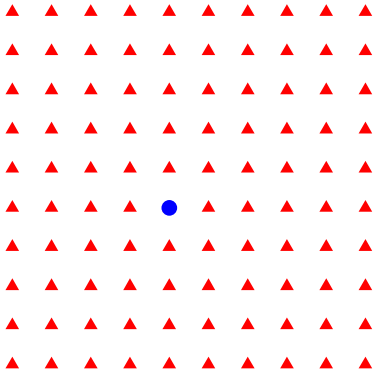


Conclusions

- **Seismic imaging with dense array should be a powerful tool to study the high-resolution 3-D structures for earthquake source region/fault/volcano, or specific regions (JUNO, Jinping), et al.**



FAST(Five-hundred meters Aperture Spherical radio Telescope)



Dense Seismic Array

- **Joint inversion with diversified geophysical data, and new observations from high-energy particle physics, may greatly improve the resolution and reliability of 3-D structure imaging for the Earth.**

Thanks a lot for your attention !