Beamforming Reliability of DAS Ambient Noise Data and Wave Type Identification

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Introduction

Urban ambient noise usually come from fixed location or direction (e.g., Dou et al., 2017; Zhang et al., 2019; Nilot et al., 2019; Li et al., 2020). Thus, to obtain an accurate estimation of the subsurface velocity model, the following problems needs to be solved

- Resolve the source propagation direction from the DAS ambient noise data;
- Identify the wave types in the DAS ambient noise data.

Challenges:

(1) Due to the measurement of DAS, amplitude projection and polarity reversal may exist in the data which may influence the beamforming results.
(2) The recorded Rayleigh and Love waves can not be separated without additional knowledge of the source.

Goal:

(1) Test the reliability of beamforming results when applied on DAS ambient noise data;
(2) Estimate the Rayleigh to Love waves ratio(RLr) in the DAS ambient noise data.

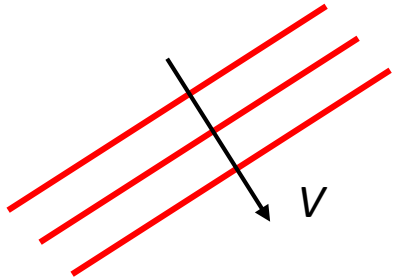
Methodology

Urban ambient noise simulation

Rayleigh wave strain (θ_i is the intersection angle between the source propagation direction and the DAS array)**:**

Point-wise:

$$s_R(x,\omega) = A\,(\omega)\sum_{i=1}^{N_s} -\frac{i\omega\cos\theta_i{}^2}{v_R(\omega)}\,a_{Ri}\,e^{-i\omega(t_i+(x\cos\theta_i)/v_R(\omega))},$$



Averaged:

$$s_{Ravg}(x,\omega) = \frac{1}{g}\int_{x-\frac{g}{2}}^{x+\frac{g}{2}} s_R(y,\omega)\,dy.$$

Love wave strain :

Receiver array

Point-wise:

$$s_L(x,\omega) = A(\omega)\sum_{i=1}^{N_s} -\frac{i\omega\,\sin\theta_i\cos\theta_i}{v_L(\omega)}\,a_{Li}\,e^{-i\omega(t_i+(x\cos\theta_i)/v_L(\omega))}\,,$$

Averaged:

$$s_{Lavg}(x,\omega) = \frac{1}{g}\int_{x-\frac{g}{2}}^{x+\frac{g}{2}} s_L(y,\omega)\,dy.$$

MUSIC beamforming *(Please refer to the Geophysics paper (Zhang et al., 2019))*

Methodology

Rayleigh to Love waves ratio estimation

Then at two positions (x_1, ω) and (x_2, ω) , we have

$$\frac{|D_1|^2}{|D_2|^2} = \frac{a^2m^2\alpha(\omega)^2+b^2+2abm\alpha(\omega)\cos(\omega(x_1e_1)\delta_v(\omega))}{c^2m^2\alpha(\omega)^2+d^2+2cdm\alpha(\omega)\cos(\omega(x_2e_2)\delta_v(\omega))}.$$

Assumptions:

(1) $|R|:|L| = m$;
(2) $\alpha(\omega)$=1.1 at high frequency band;
(3) We simplified the cross-term by neglecting the difference of t_i between different sources.

$|R|:|L| = m, m$ is what need to be solved.

$$R(x,\omega) = \frac{1}{g}\int_{x-\frac{g}{2}}^{x+\frac{g}{2}} \sum_{i=1}^{N_s} a_{Ri}\, e^{-i\omega(t_i+y\cos\theta/v_R(\omega))}dy\,.$$

$$\alpha(\omega) = \frac{v_L(\omega)}{v_R(\omega)}$$

$$e_1 = \cos(\theta_1)$$

$$L(x,\omega) = \frac{1}{g}\int_{x-\frac{g}{2}}^{x+\frac{g}{2}} \sum_{i=1}^{N_s} a_{Li}\, e^{-i\omega(t_i+y\cos\theta/v_L(\omega))}dy\,.$$

$$\delta_v(\omega) = \frac{1}{v_R(\omega)} - \frac{1}{v_L(\omega)}$$

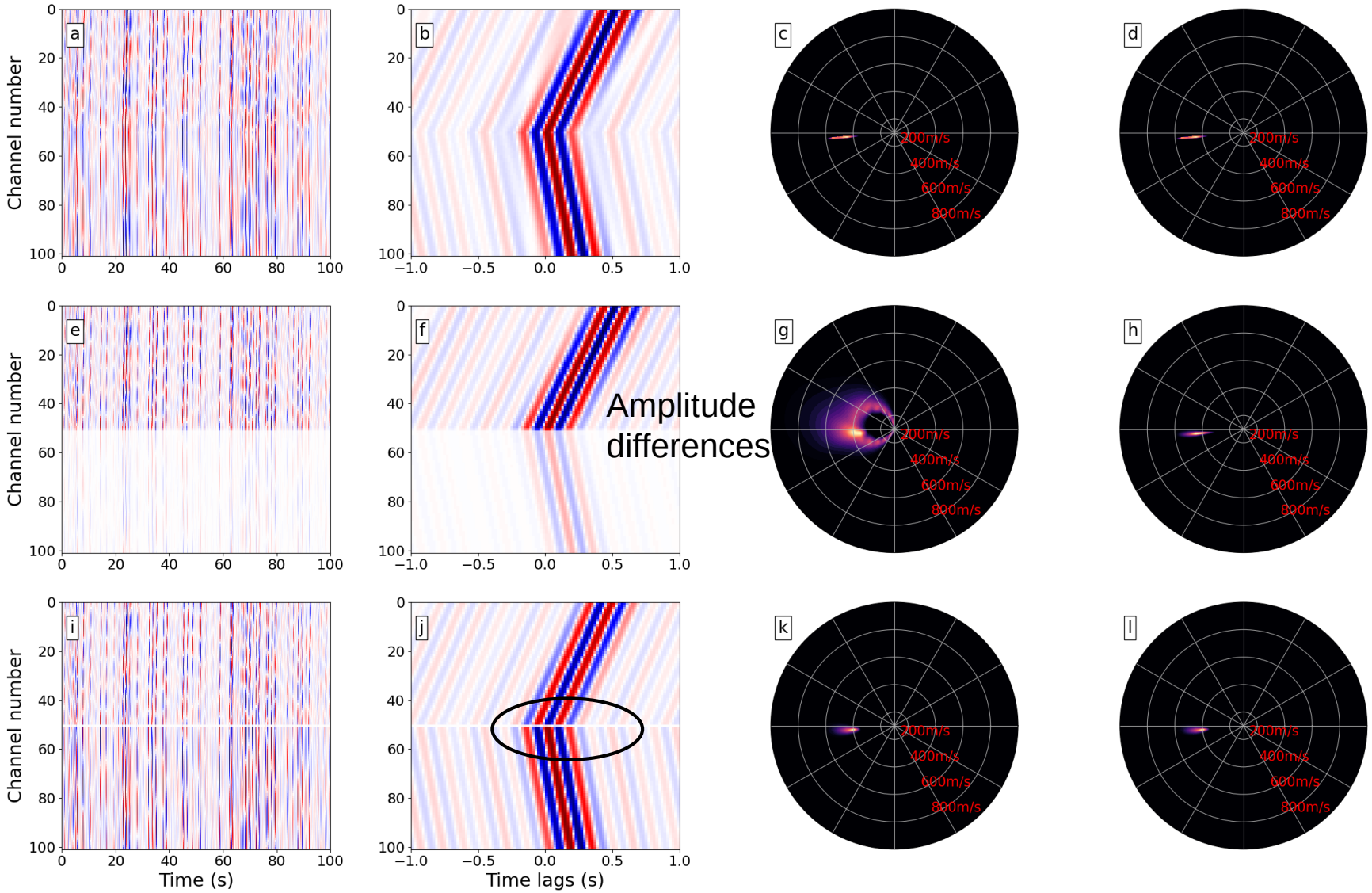
$$e_2 = \cos(\theta_2)$$

Synthetic data examples

Vertical displacement

Rayleigh wave strain

Love wave strain

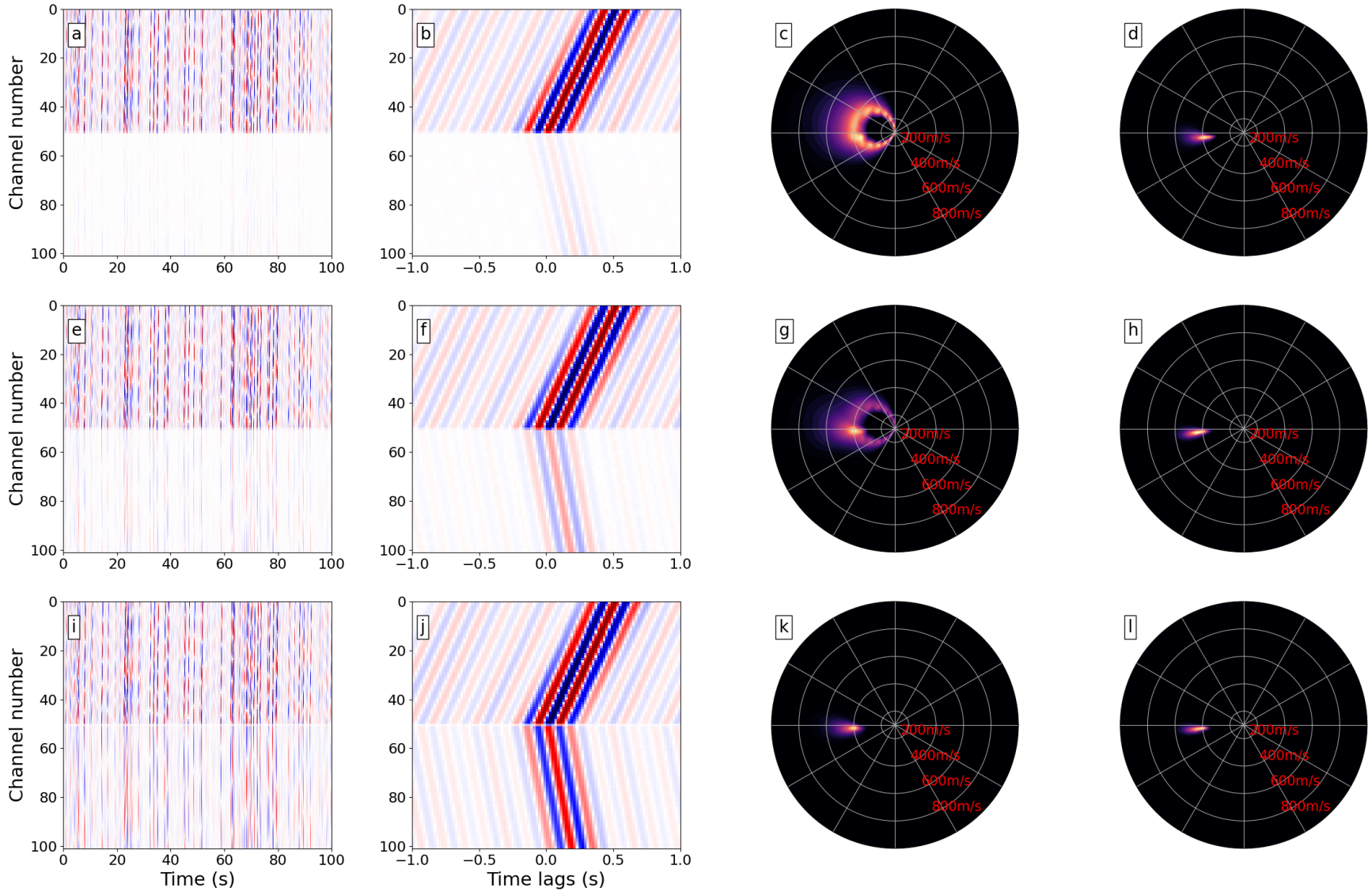


Synthetic data examples

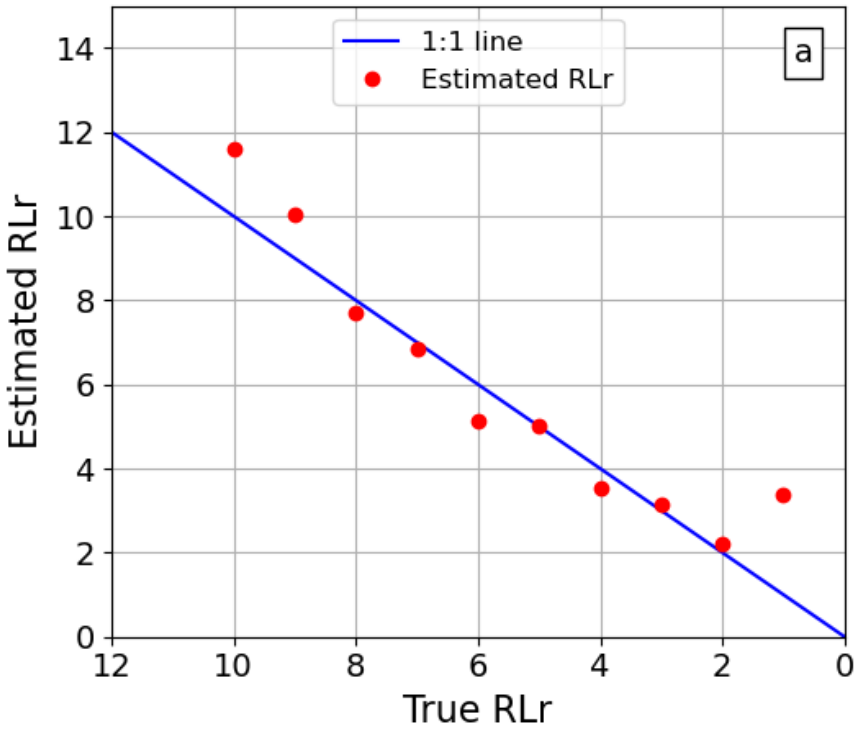
RLr=3

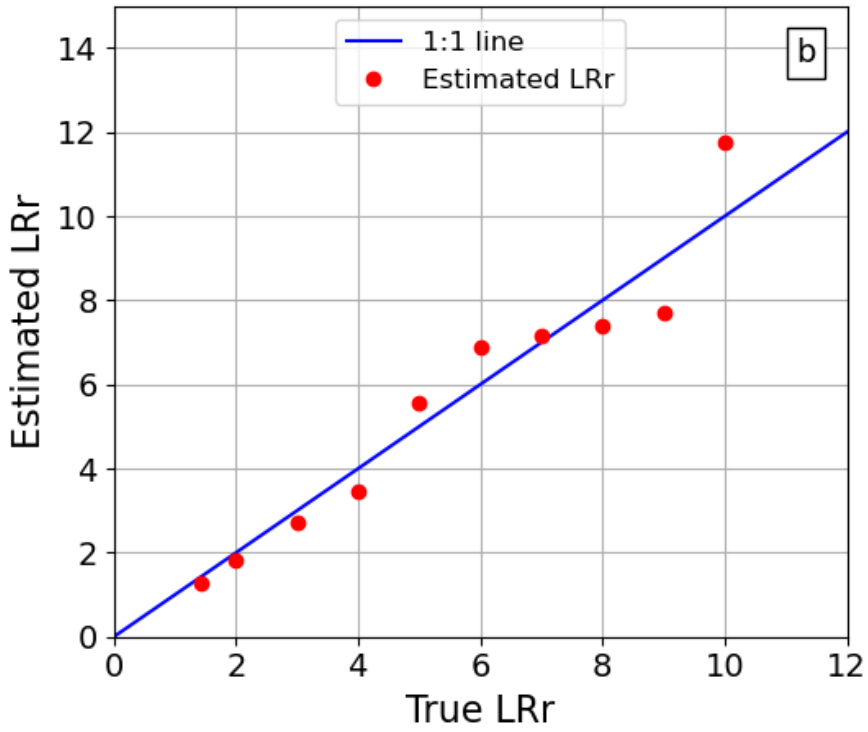
RLr=1

RLr=1/3

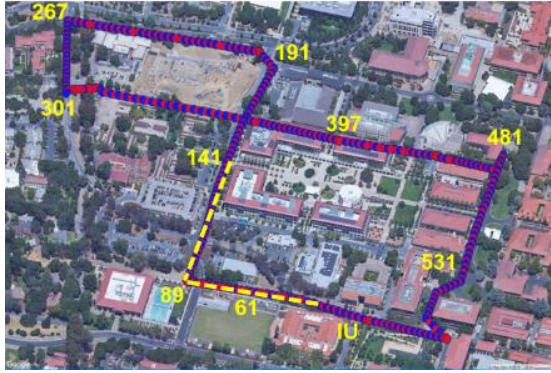


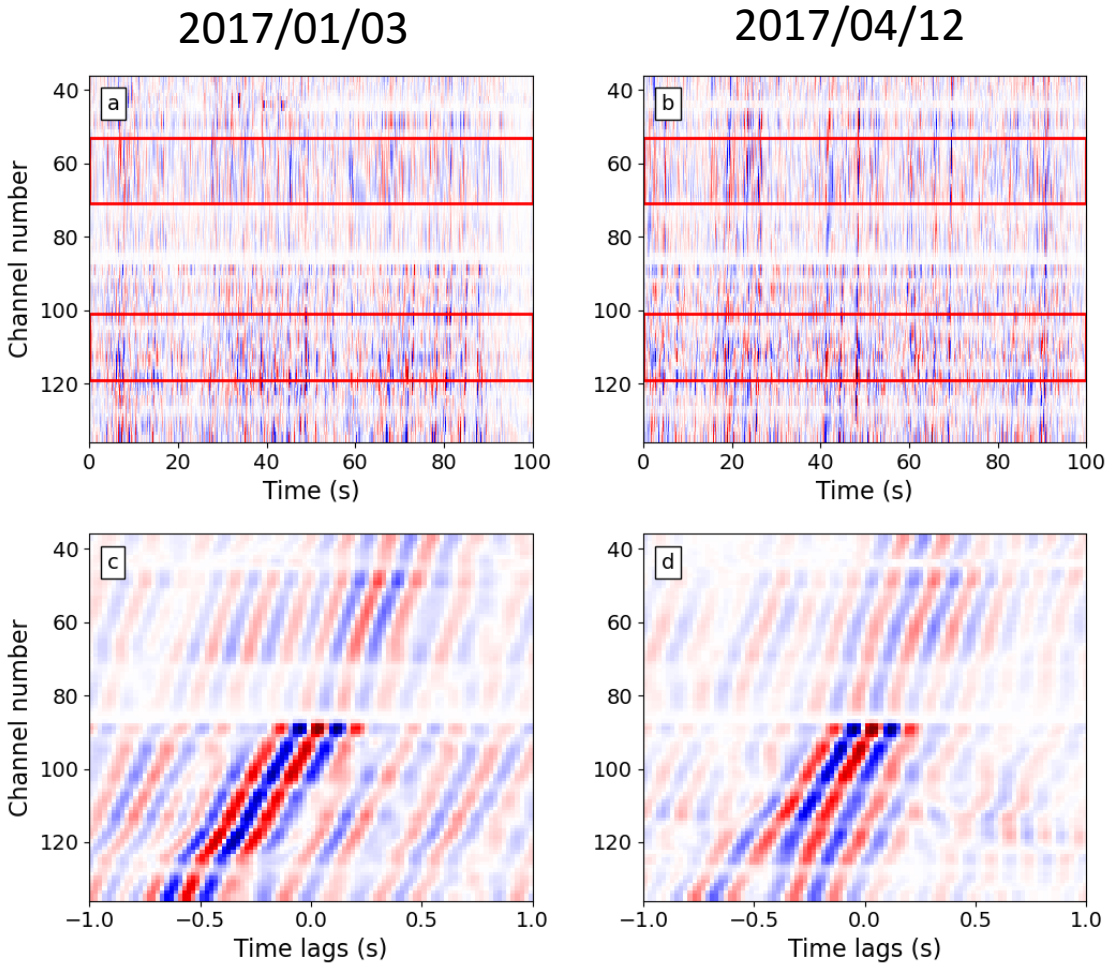
Synthetic data examples

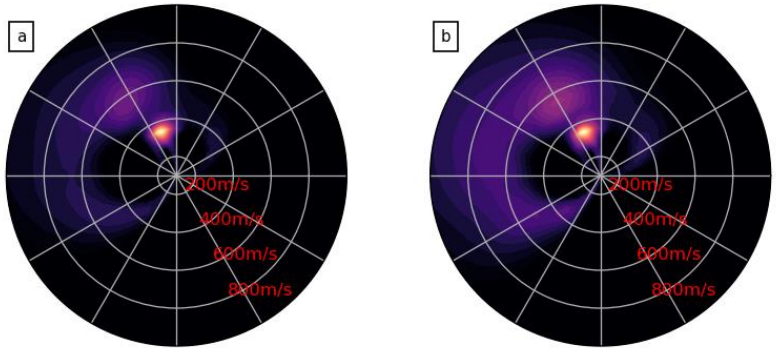




Field data examples







(a) 111°
(b) 112°

We assume that 0° starts from the East and increases anti-clockwise.

With the data marked by the red box, we estimate the RLr in the two 100-second DAS ambient noise data as RLr=0.7 and RLr=0.47, respectively.

Conclusions

(1) Beamforming results are reliable when applied on DAS ambient noise data if the sources mainly come from one direction and the DAS ambient noise data are properly processed.

(2) We estimate the Rayleigh to Love waves ratio from the DAS ambient noise data with the ambient noise wavefield propagation direction and amplitude information of the data.

Thank you!
Welcome Questions and suggestions!

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