Mitigating array-induced bias in ambient noise beamforming

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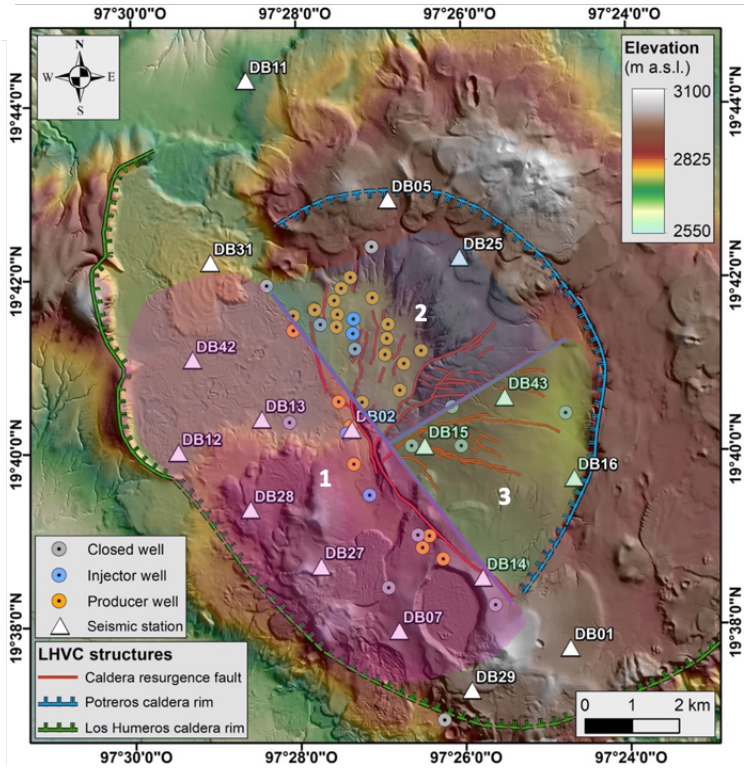
Fraunhofer IEG

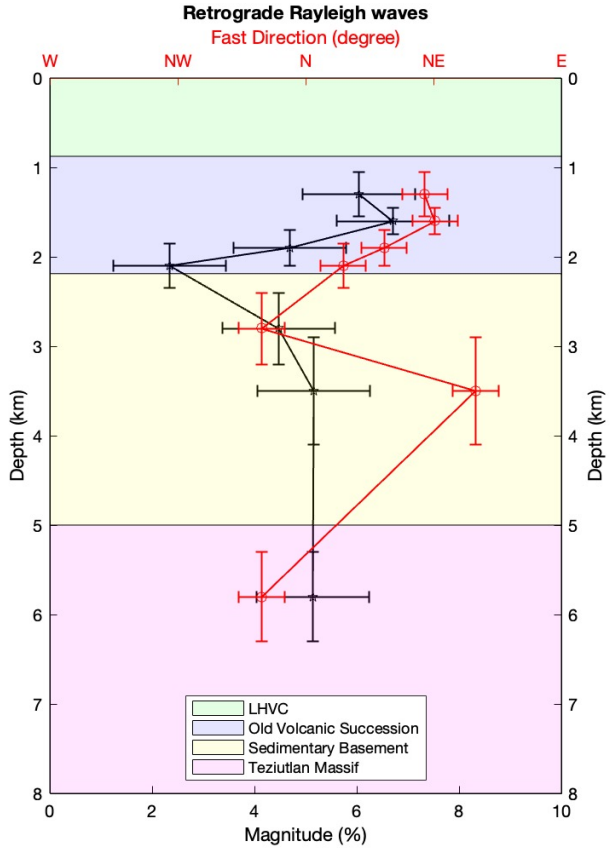
Anisotropy analysis with beamforming

Constraints on fractures in a geothermal system

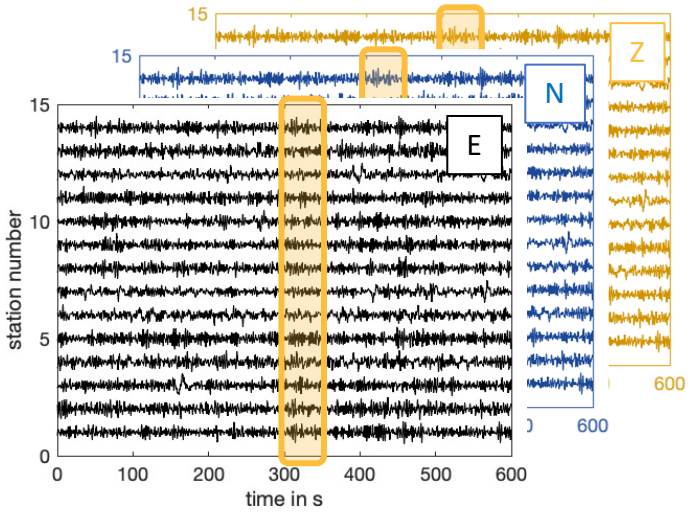
Kennedy et al., *Solid Earth*, 2022 (submitted)

EGU2022-2940

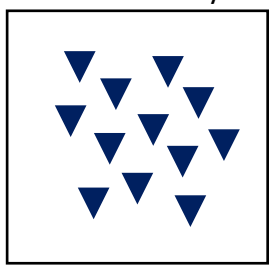




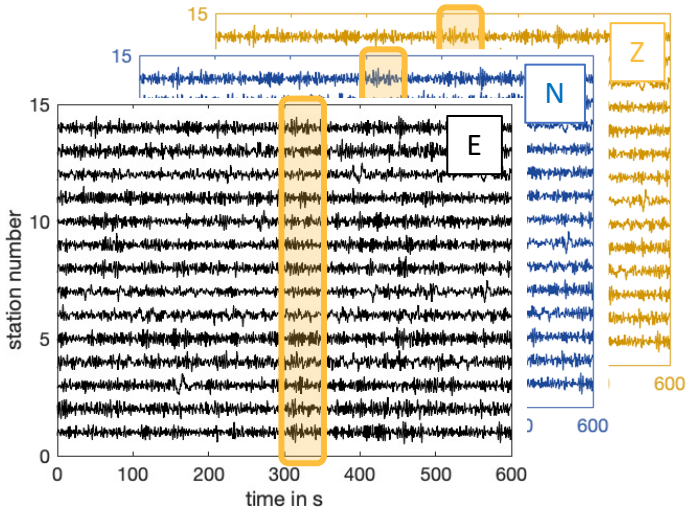
Three-component beamforming



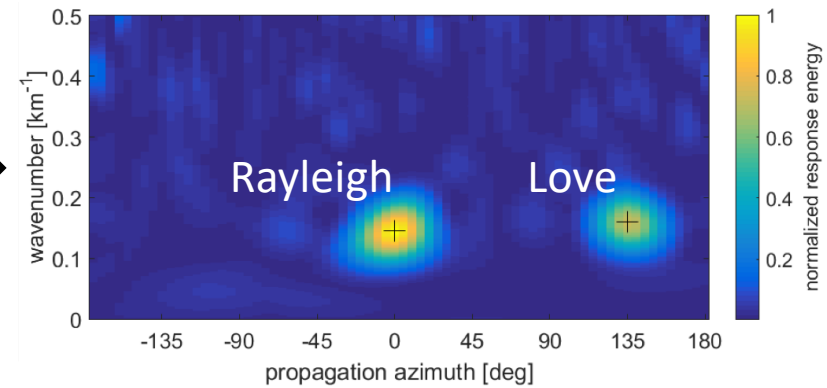
Seismic array



Three-component beamforming



one time window



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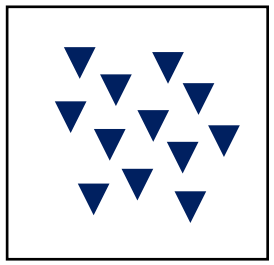
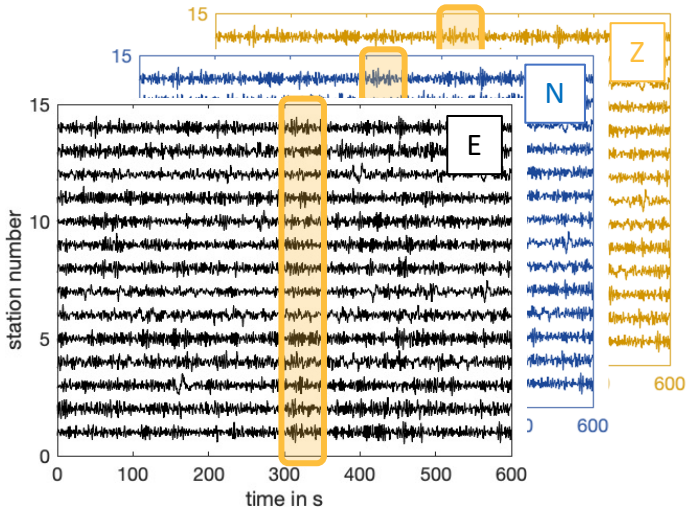
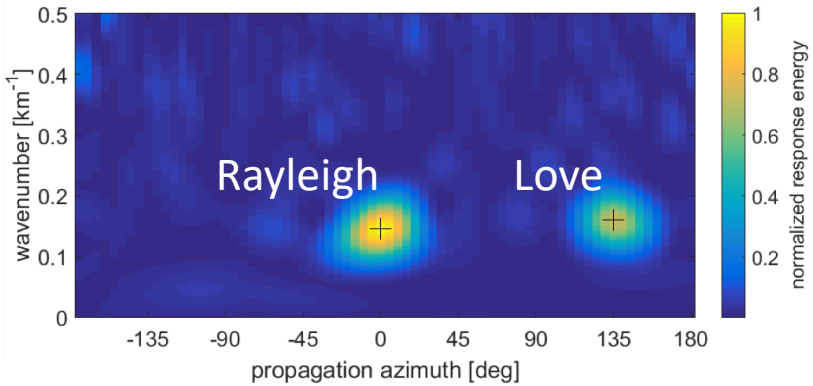


Three-component beamforming



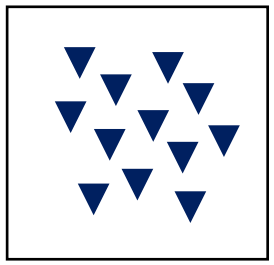
one time window



all times & frequencies

- Dispersion curves
- **Anisotropy**
- Wavefield composition

Seismic array



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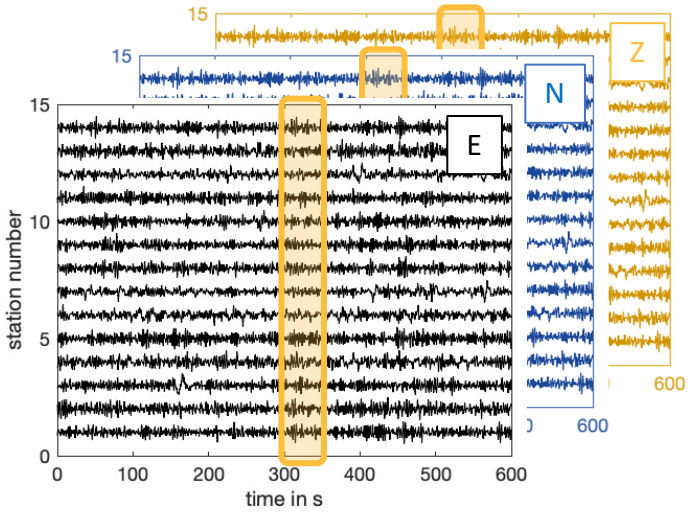

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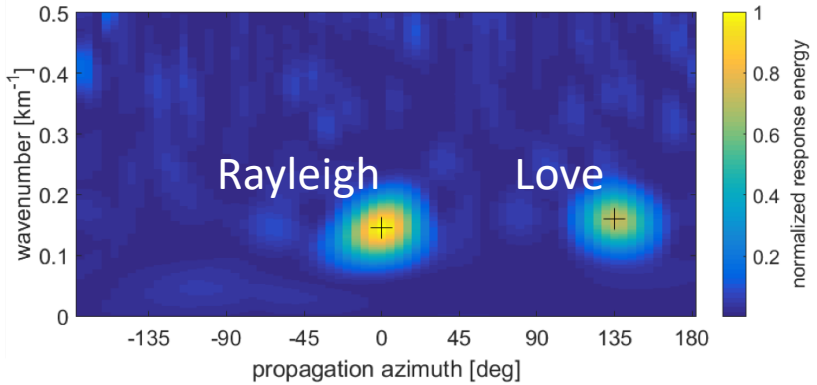

all times & frequencies

- Dispersion curves
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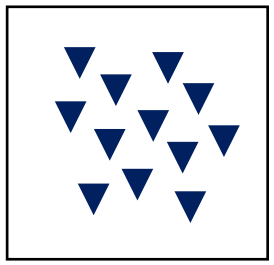
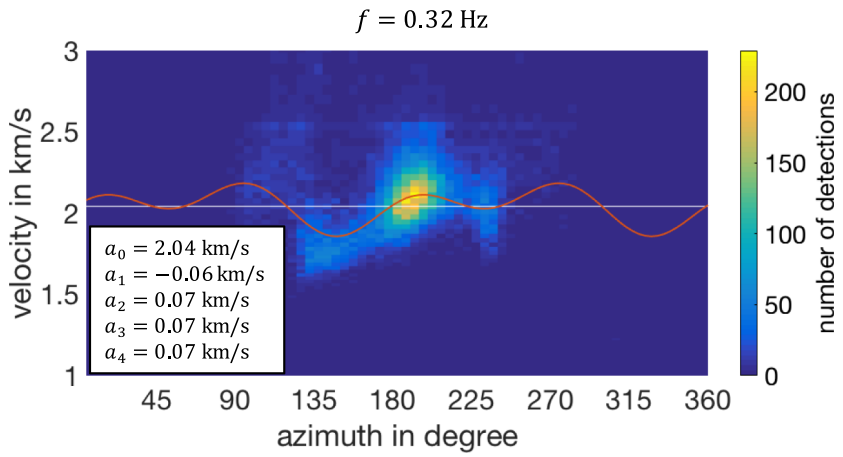
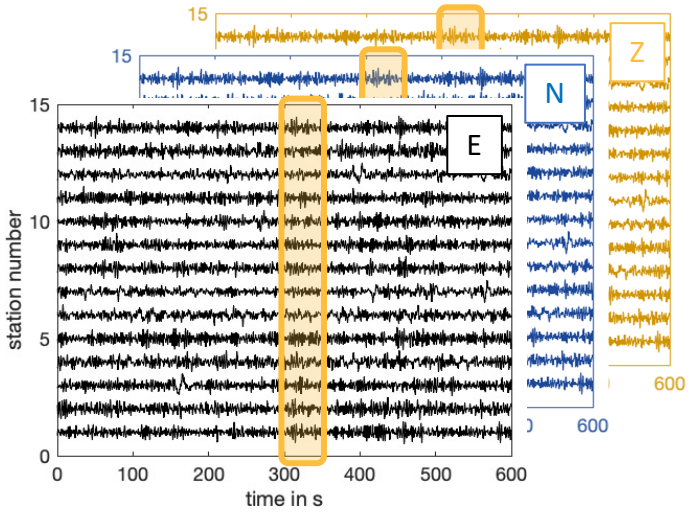




Löer et al., *Geophys. J. Int.*, 2018

Three-component beamforming



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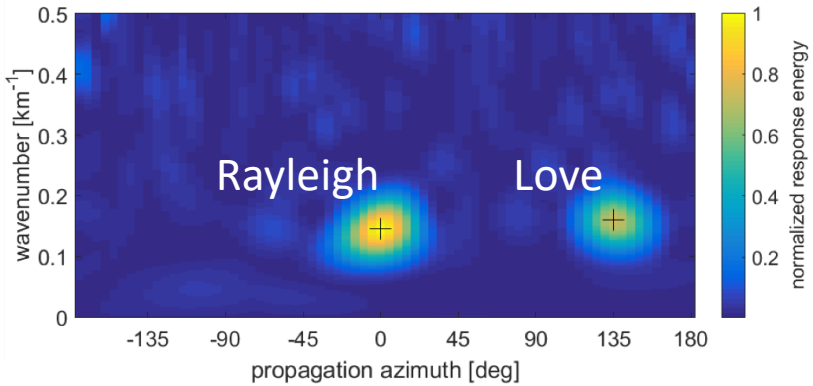
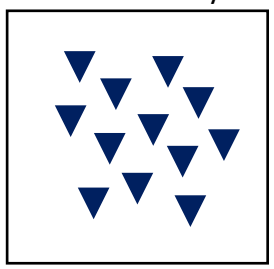
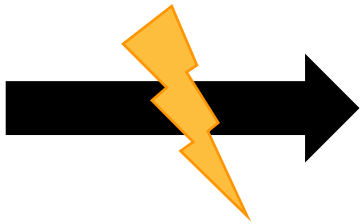


all times & frequencies

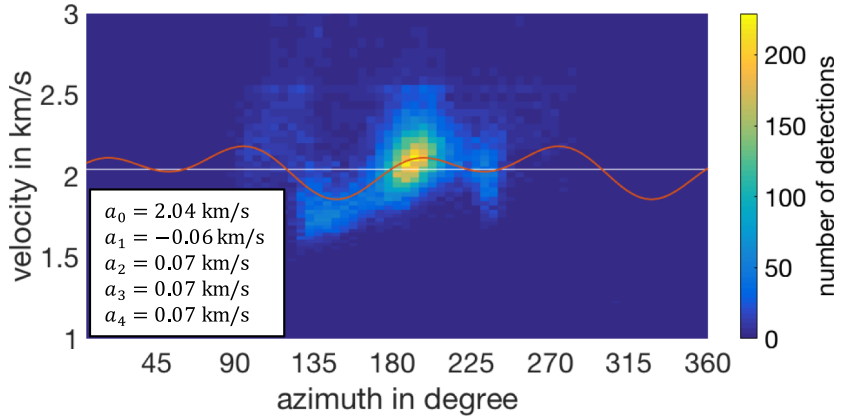
- Dispersion curves
- **Anisotropy**
- Wavefield composition

Seismic array





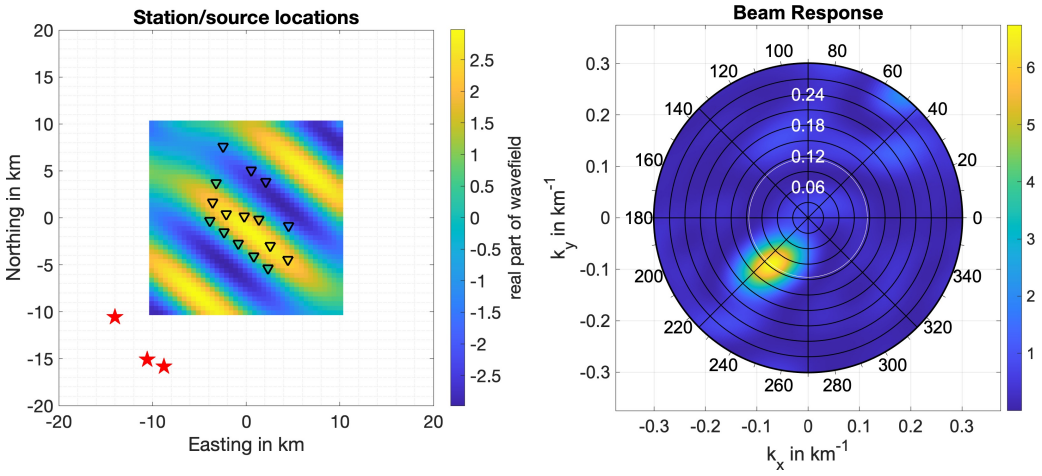
$f = 0.32$ Hz



Löer et al., *Geophys. J. Int.*, 2018

Array-induced bias

Model isotropic wavefields:



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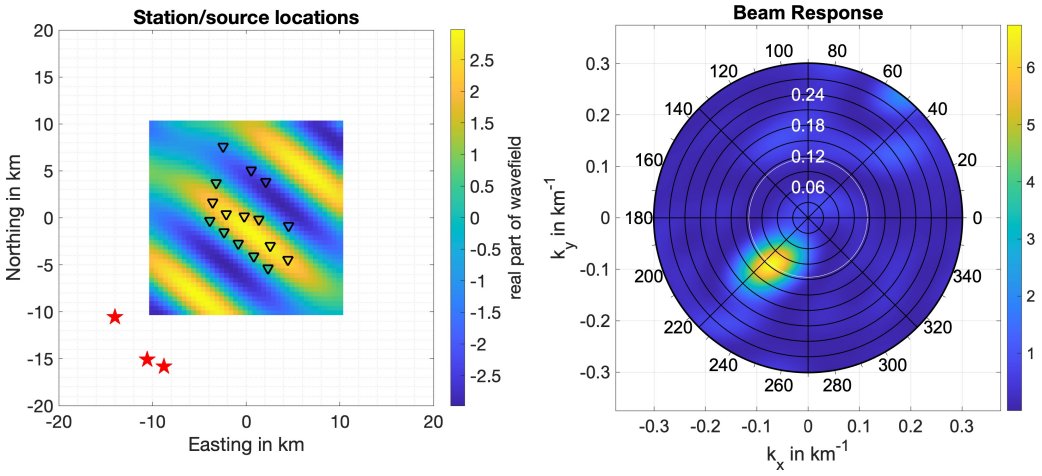
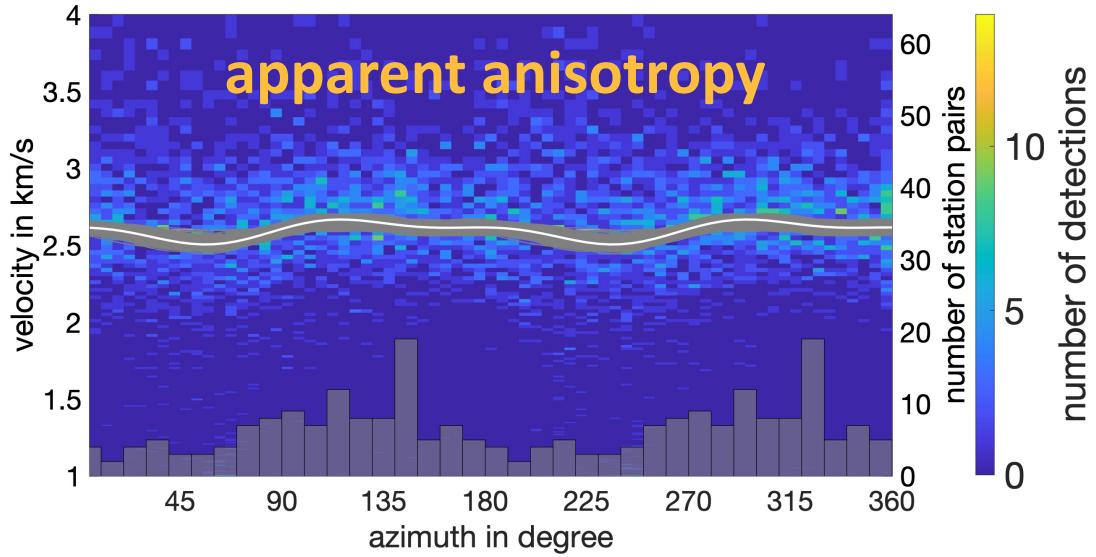
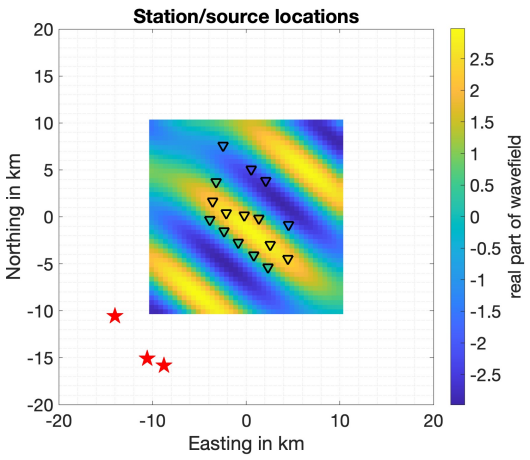


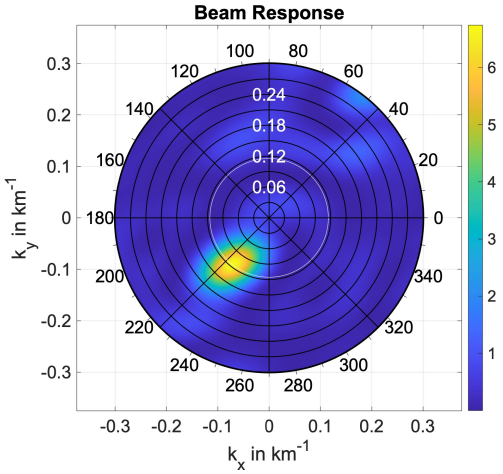
Analyse with beamformer:



Array-induced bias

Model isotropic wavefields:





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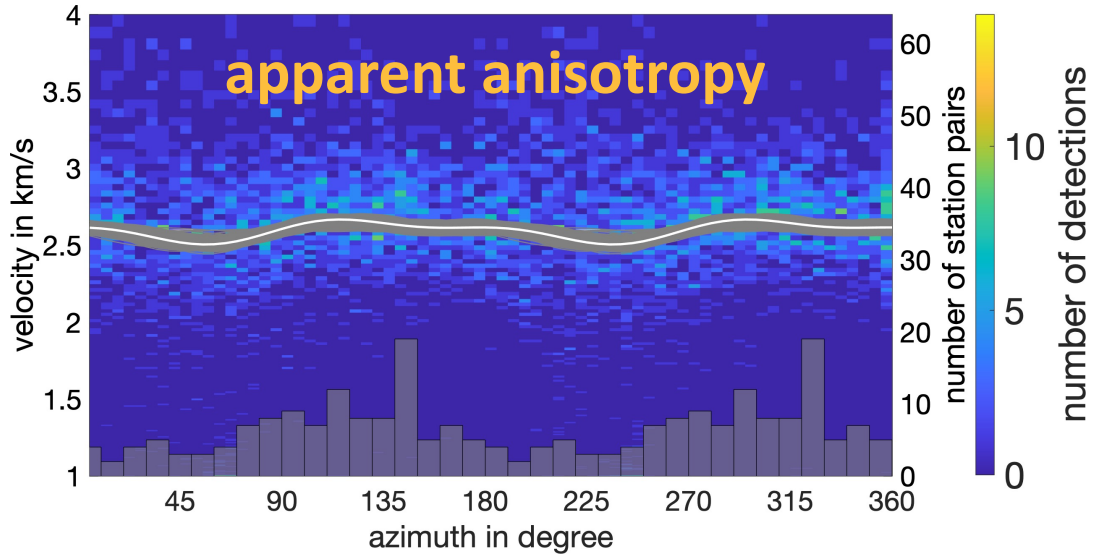


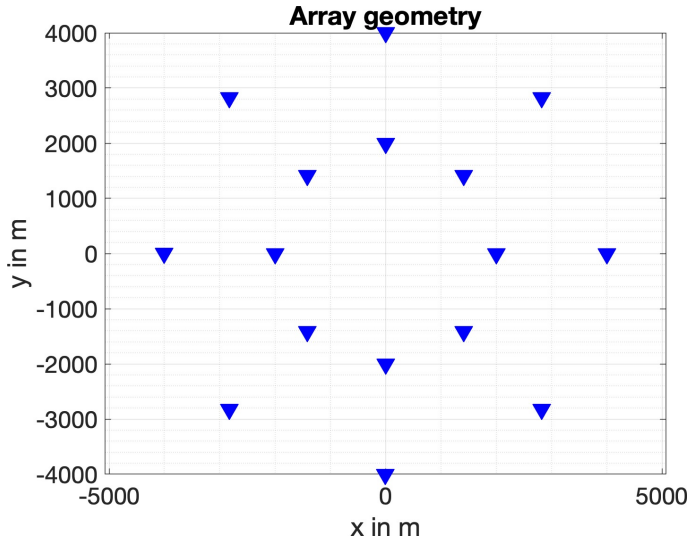
(1) modify **array design**

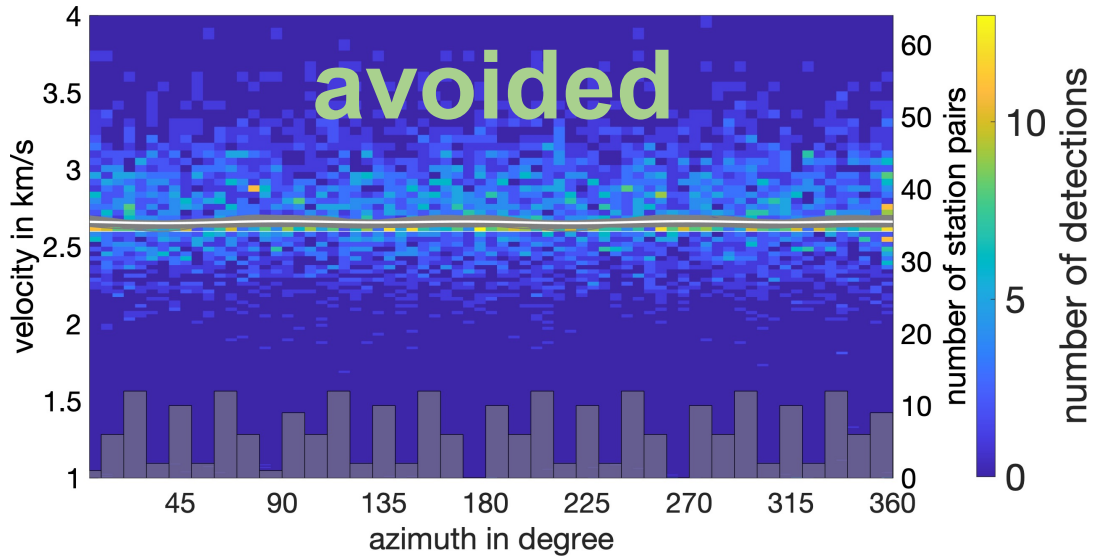
(2) correct **array response**

(3) correct **anisotropy curve**

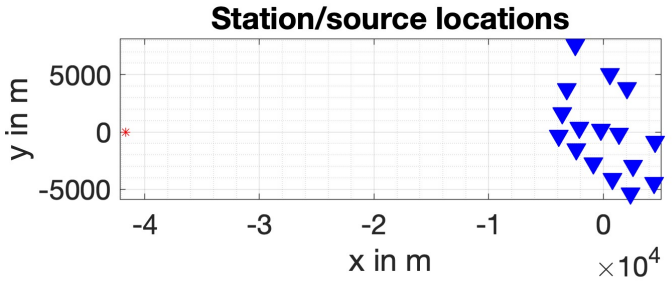
(1) Avoiding apparent anisotropy

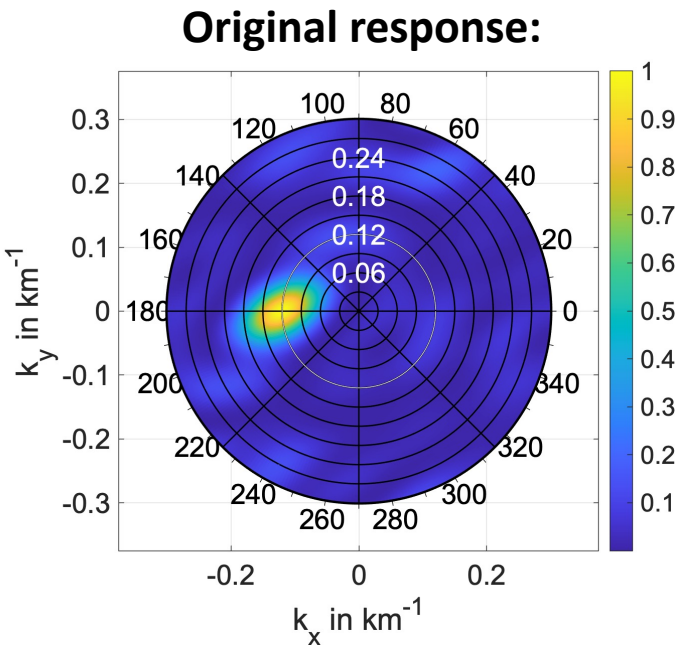
→ **isotropic array design:**





(2) Correcting the array response





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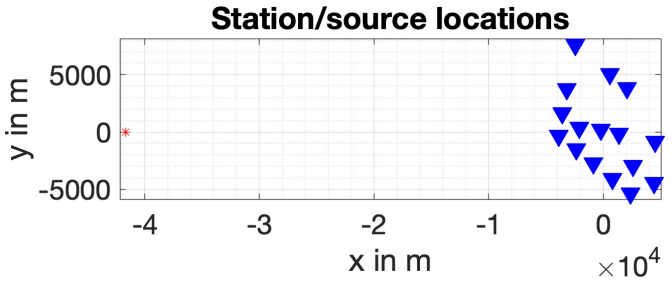
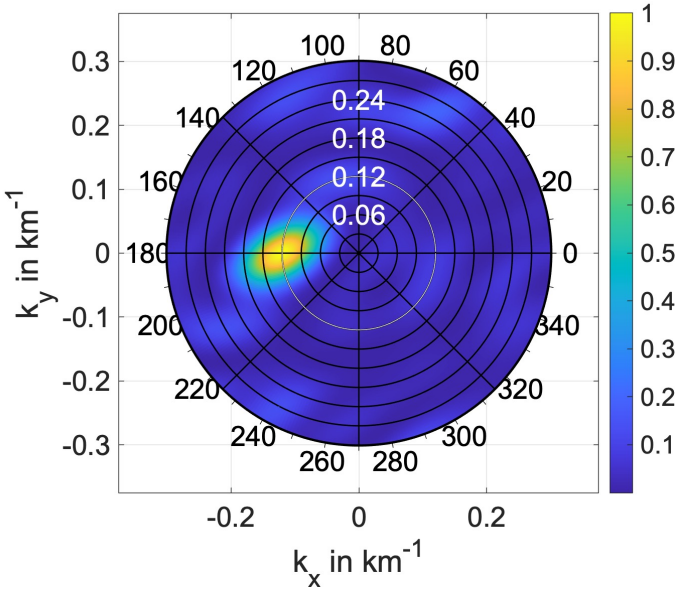


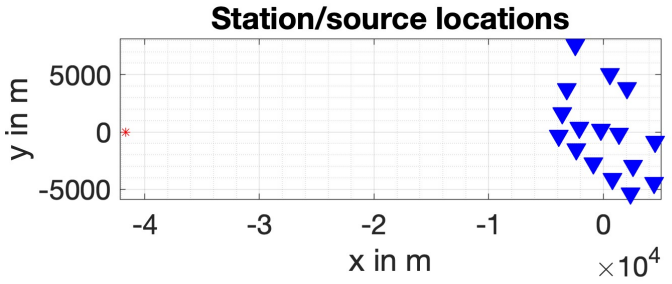
Original response:



Array response matrix = matrix of **station-pair** cross-correlations

$$\begin{matrix} s_1 s_1^* & s_1 s_2^* & s_1 s_3^* \\ s_2 s_1^* & s_2 s_2^* & \\ s_3 s_1^* & & \end{matrix}$$

(2) Correcting the array response



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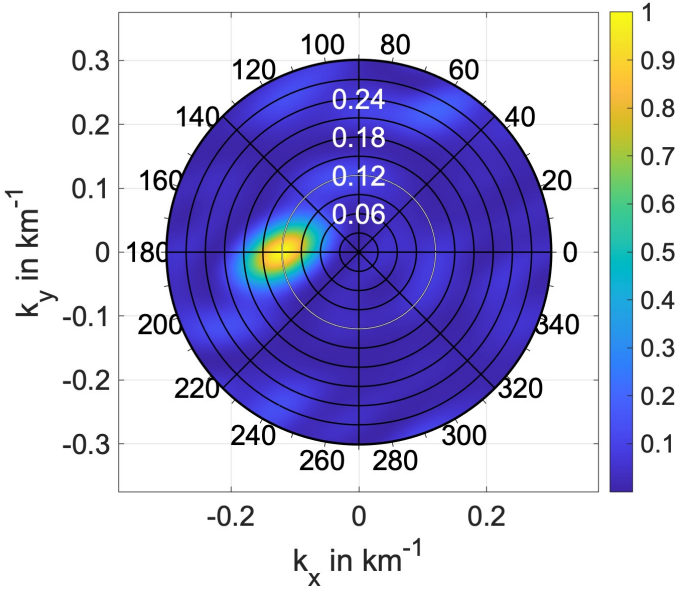
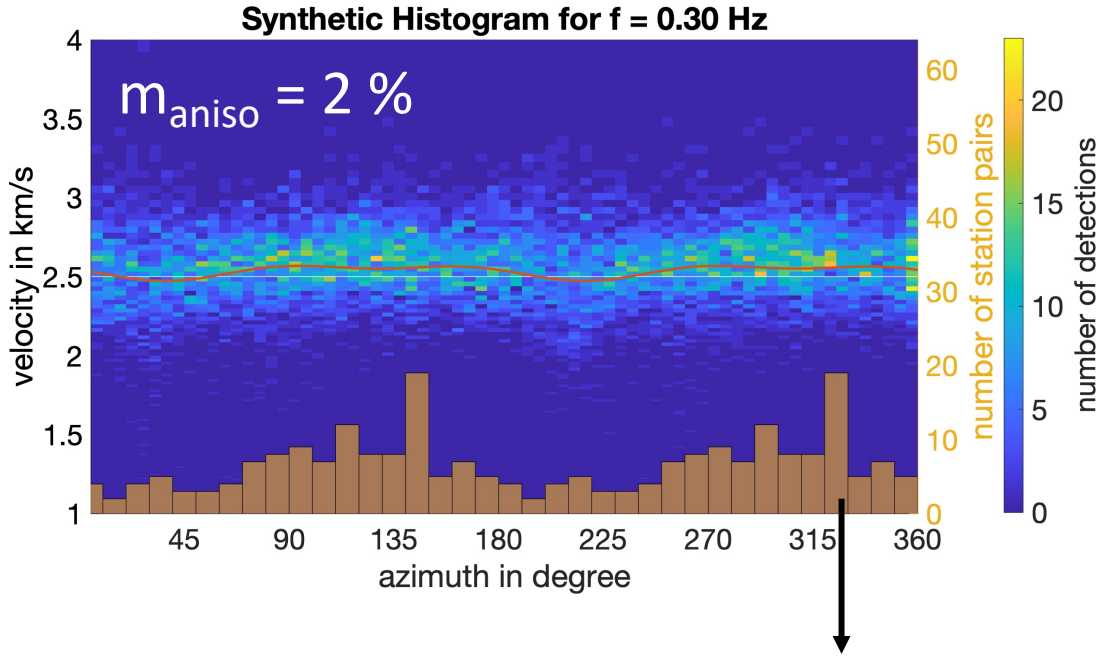


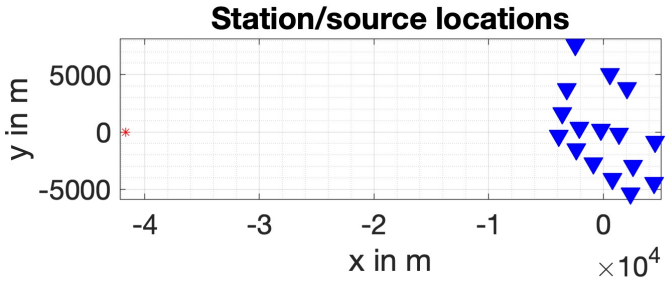


Array response matrix = matrix of **station-pair** cross-correlations

$$\begin{matrix} s_1 s_1^* & s_1 s_2^* & s_1 s_3^* \\ s_2 s_1^* & s_2 s_2^* & \\ s_3 s_1^* & & \end{matrix}$$

distribution of **station-pair** orientations

(2) Correcting the array response



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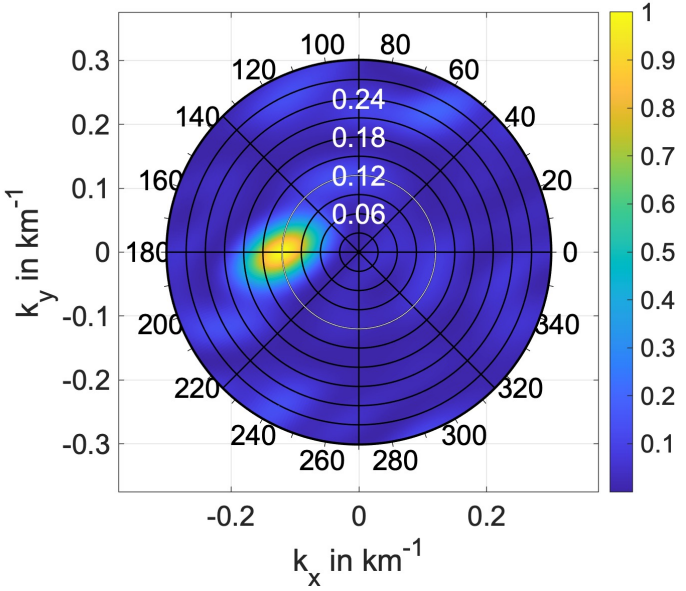
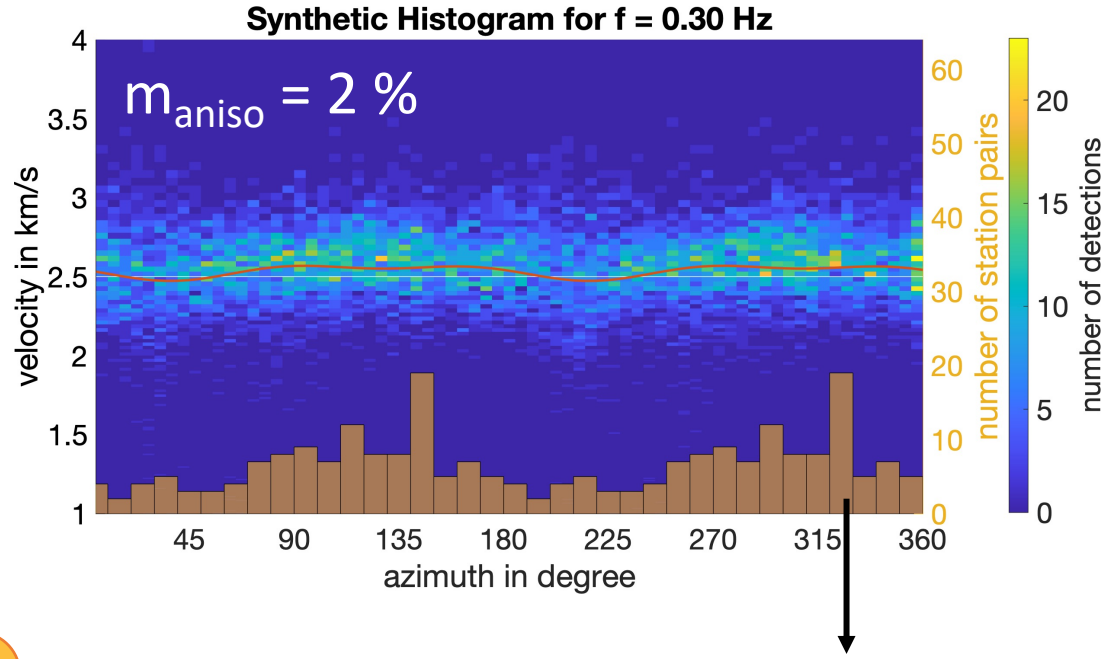




Array response matrix = matrix of **station-pair** cross-correlations

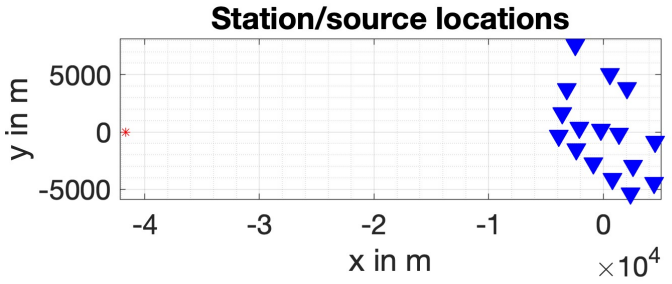
$$\begin{matrix} s_1s_1^* & s_1s_2^* & s_1s_3^* \\ s_2s_1^* & s_2s_2^* & \\ s_3s_1^* & & \end{matrix} \quad \mathbf{x} \quad \begin{matrix} w_{11} & w_{12} & w_{13} \\ w_{21} & w_{22} & \\ w_{31} & & \end{matrix}$$

Scaling matrix ← distribution of **station-pair** orientations

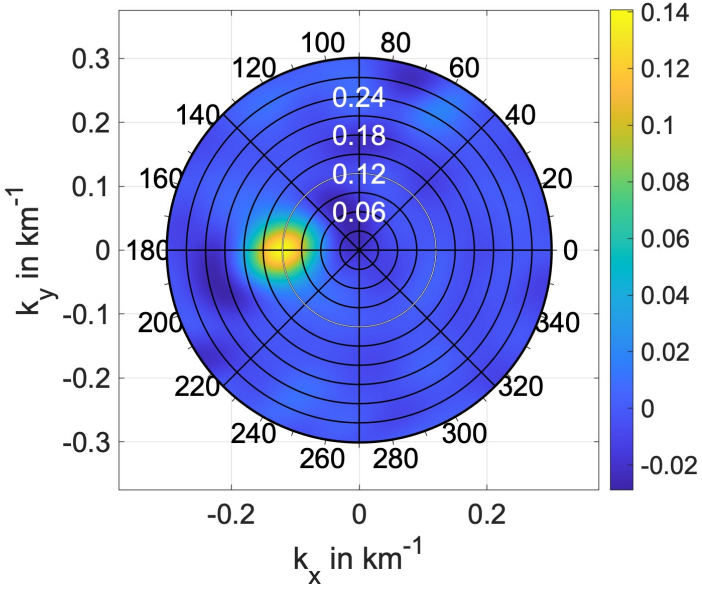
use to **scale**

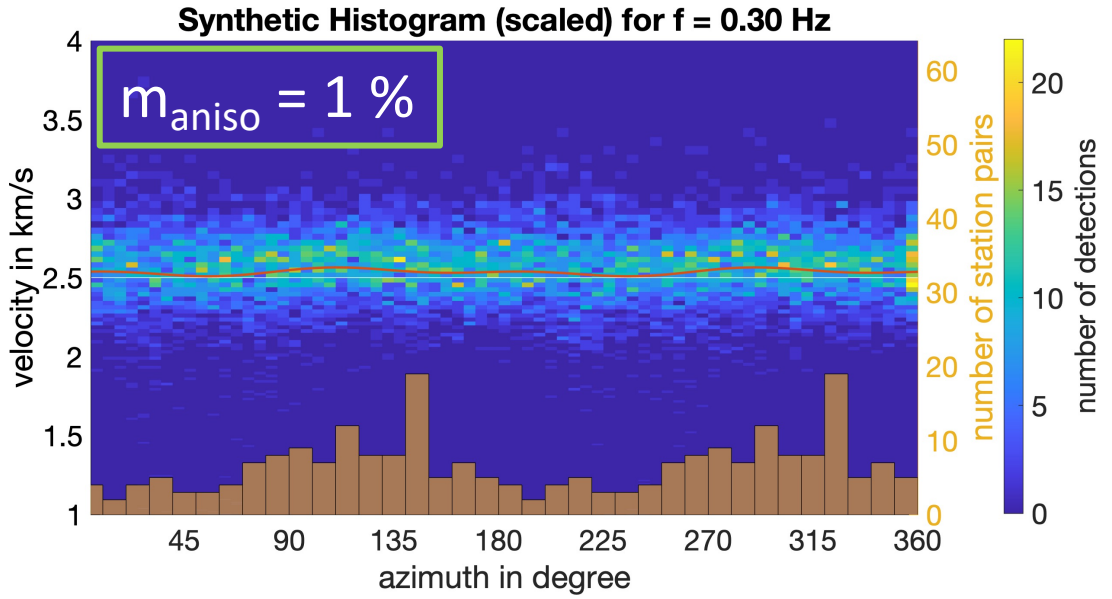
overrepresented orientations

(2) Correcting the array response



Corrected response:





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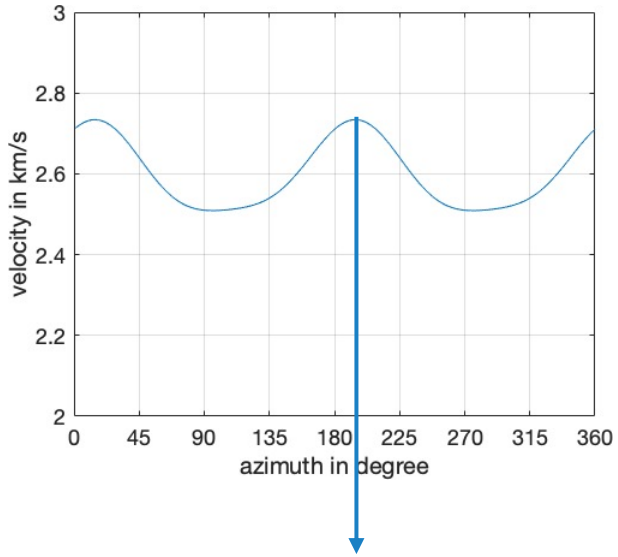
$$\begin{matrix} s_1 s_1^* & s_1 s_2^* & s_1 s_3^* \\ s_2 s_1^* & s_2 s_2^* & \\ s_3 s_1^* & & \end{matrix} \quad \mathbf{X} \quad \begin{matrix} w_{11} & w_{12} & w_{13} \\ w_{21} & w_{22} & \\ w_{31} & & \end{matrix}$$

Scaling matrix

(3) Correcting the anisotropy curve

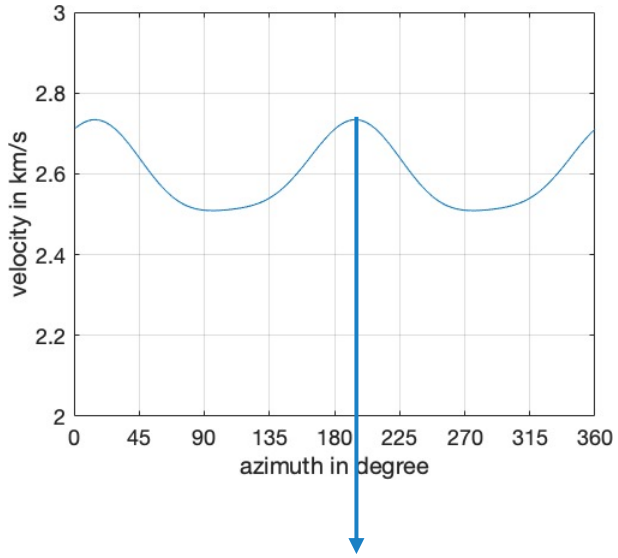
Observed anisotropy



194 degree

(3) Correcting the anisotropy curve

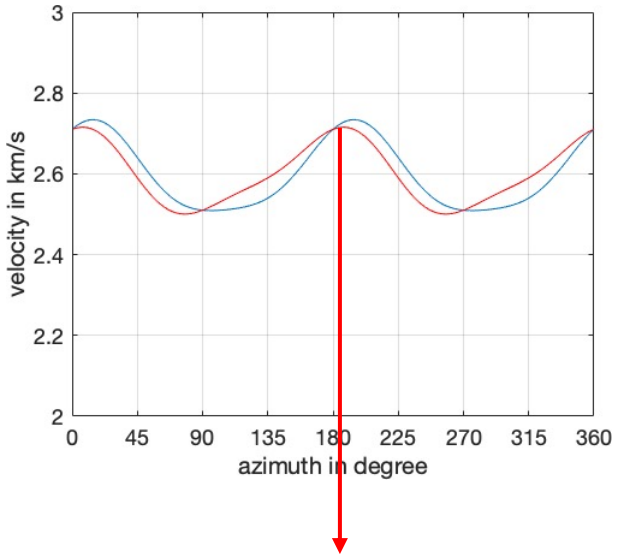
Observed anisotropy



194 degree

-

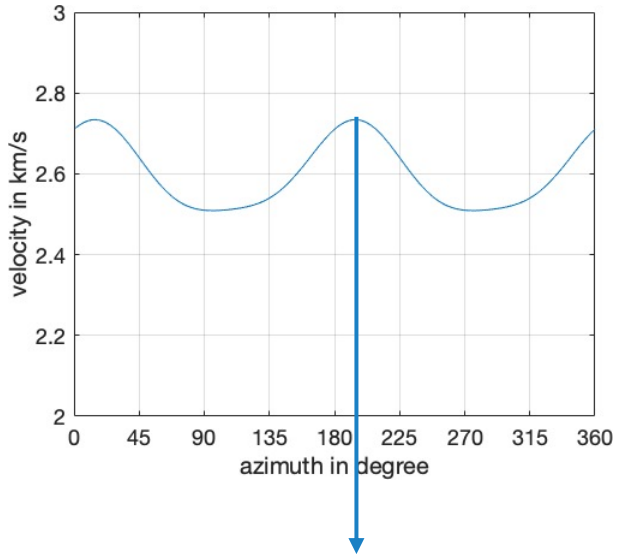
Apparent anisotropy



187 degree

(3) Correcting the anisotropy curve

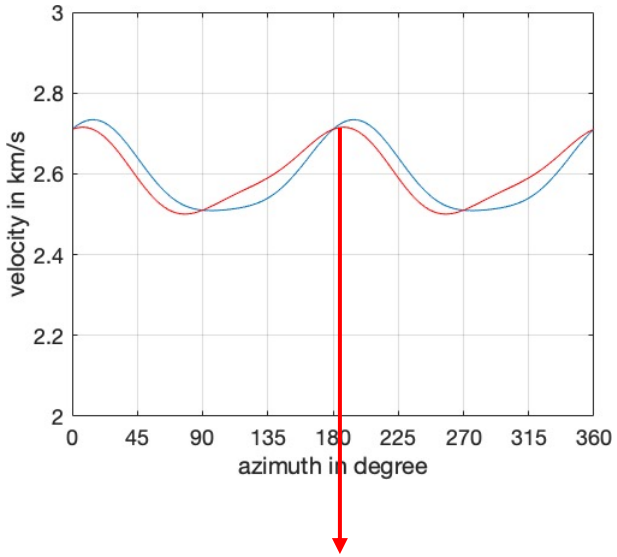
Observed anisotropy



194 degree

-

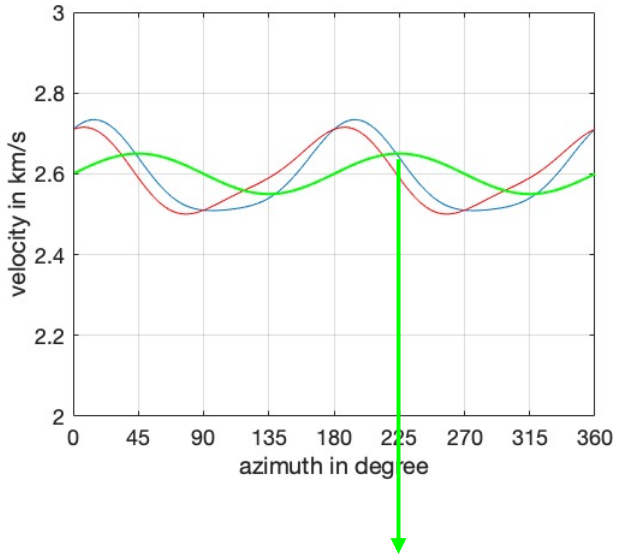
Apparent anisotropy



187 degree

=

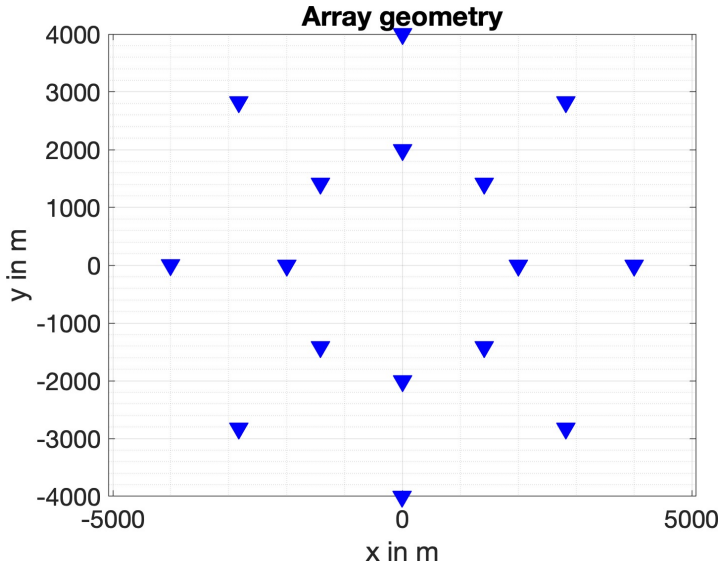
Corrected anisotropy

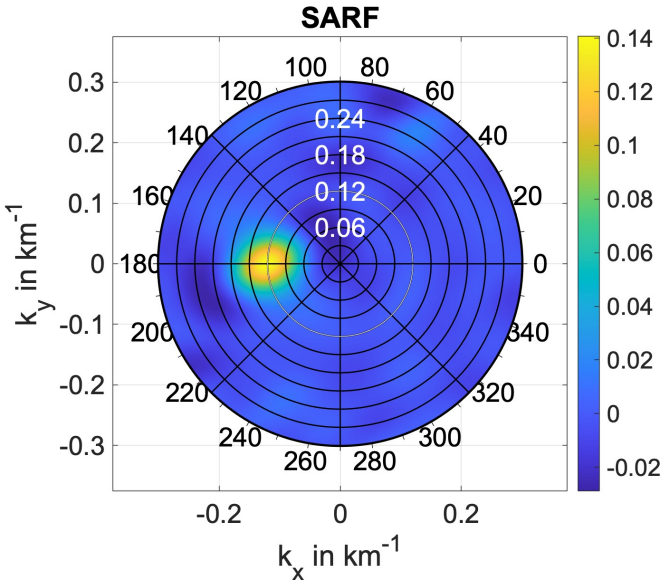


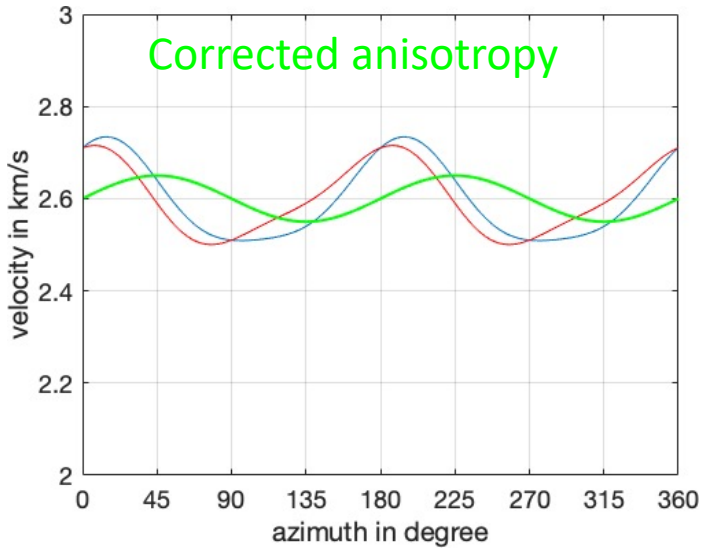
225 degree

$$v_{cor} = a_0 + (a_1 - b_1)\cos 2\theta + (a_2 - b_2)\sin 2\theta + (a_3 - b_3)\cos 4\theta + (a_3 - b_4)\sin 4\theta$$

Summary: Address Apparent Anisotropy





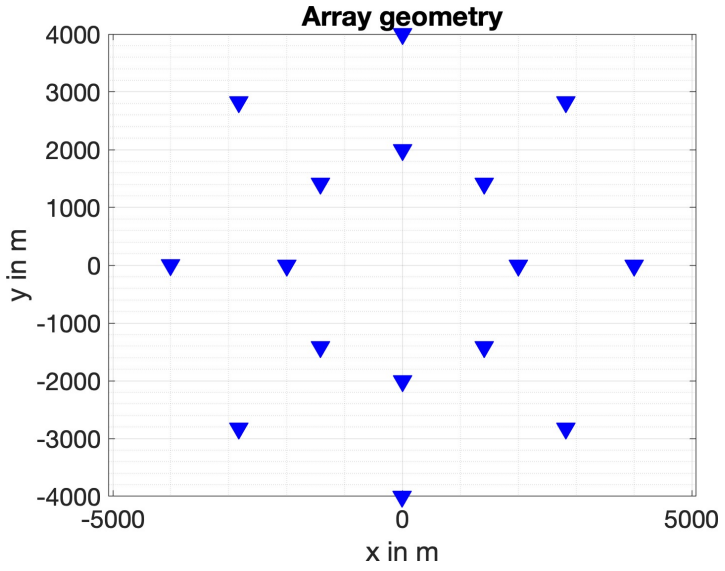


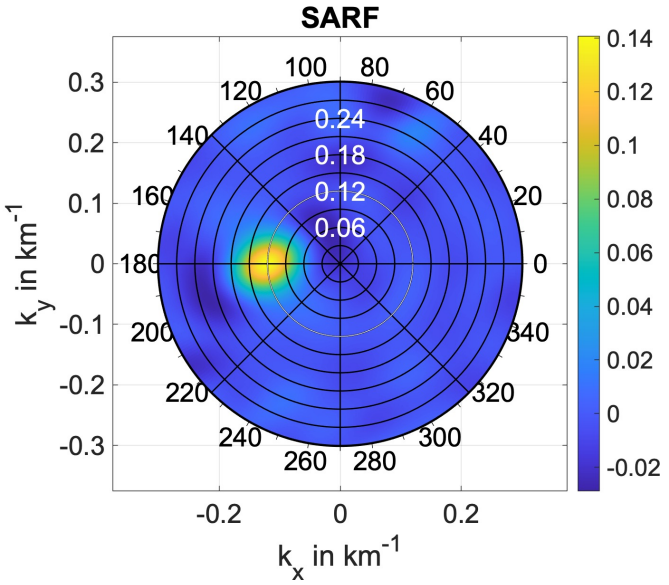
(1) Choose isotropic **array design**

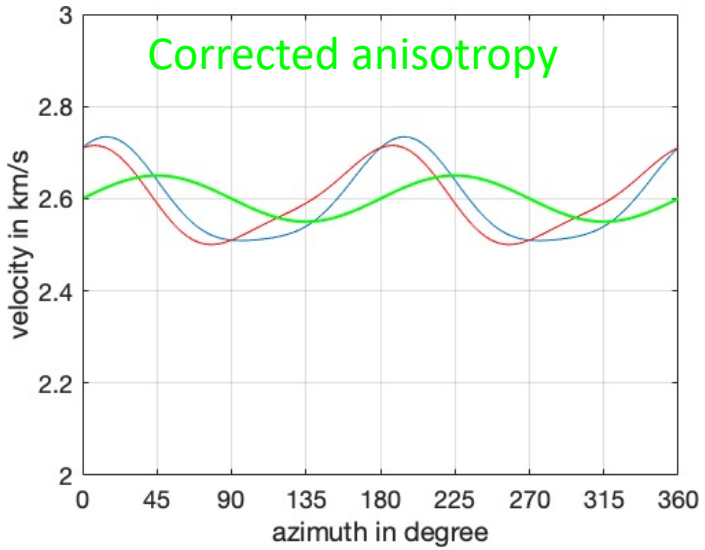
(2) Correct **array response**

(3) Correct **anisotropy curve**

Summary: Address Apparent Anisotropy







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(3) Correct **anisotropy curve**

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Claudia Finger et al:
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