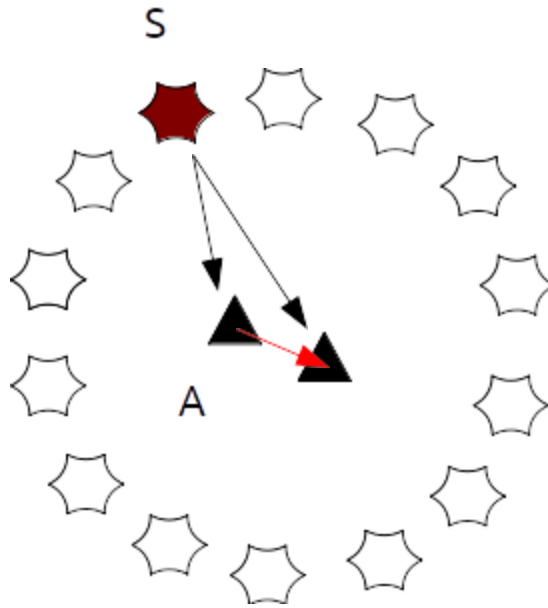


Seismic surface wave focal spot imaging: resolution tests using time-reversal simulations

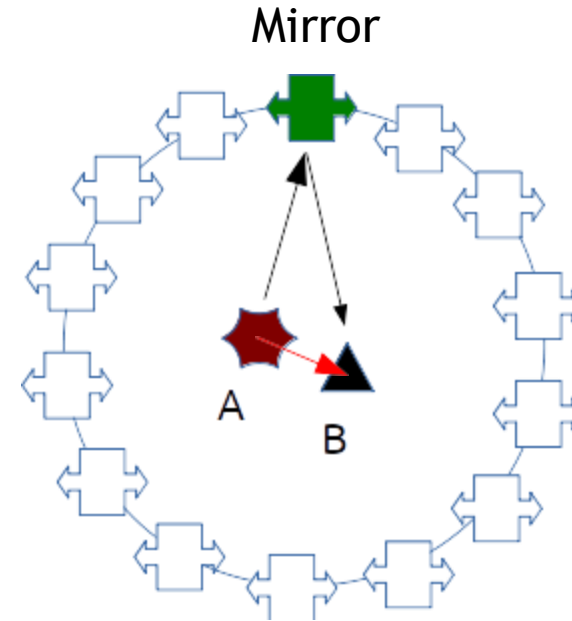
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How to simulate a focal spot using time-reversal simulation ?



Cross-correlation of a diffuse wave-field



Time-reversal simulation

Computation

AXITRA: Green's function calculator in elastic half-spaces

F. Cotton and Coutant O., 1997, Dynamic stress variations due to shear faults in a plane-layered medium,
GEOPHYSICAL JOURNAL INTERNATIONAL, Vol 128, 676-688

+

High Performance Computing provided by IT4Science

Nonlinear least square method and parameterization

$$\phi^R(r, \omega) = \begin{bmatrix} \phi_{ZZ}^R & \phi_{ZR}^R & \phi_{ZT}^R \\ \phi_{RZ}^R & \phi_{RR}^R & \phi_{RT}^R \\ \phi_{TZ}^R & \phi_{TR}^R & \phi_{TT}^R \end{bmatrix} = P^R(\omega) \\ \times \begin{bmatrix} J_0(\omega r/c_R) & -RJ_1(|\omega|r/c_R) & 0 \\ RJ_1(|\omega|r/c_R) & R^2[J_0(\omega r/c_R) - J_2(\omega r/c_R)]/2 & 0 \\ 0 & 0 & R^2[J_0(\omega r/c_R) + J_2(\omega r/c_R)]/2 \end{bmatrix}$$

Haney, M. M., & Nakahara, H. (2014).
Surface-wave Green's tensors in the near
field. *Bulletin of the Seismological Society
of America*, 104(3), 1578-1586.
<https://doi.org/10.1785/0120130113>

Nonlinear least square regression performed using
`Scipy.optimize.least_squares`

Parameterization of the wave number

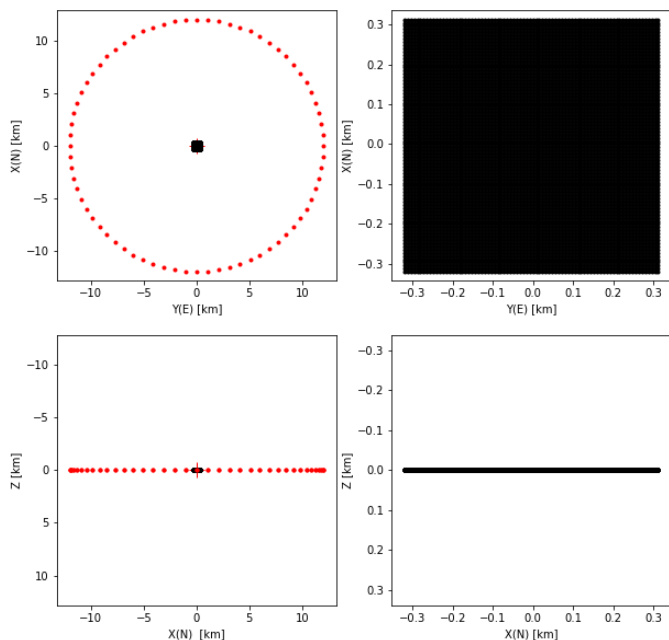
$$k(\theta) = k_0 + \sum_{n=1}^N a_n \cos(n\theta) + b_n \sin(n\theta)$$

$$\phi_{ZZ}(r, k(\theta)) = AJ_0(k(\theta)r)$$

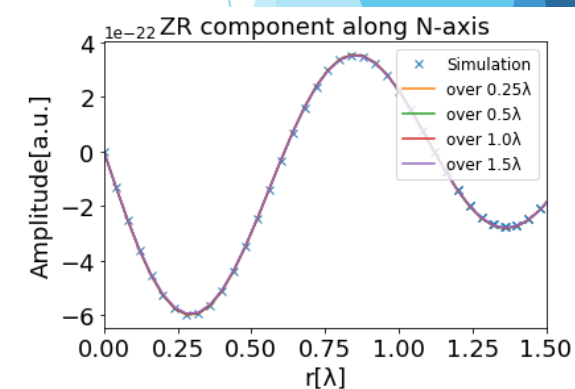
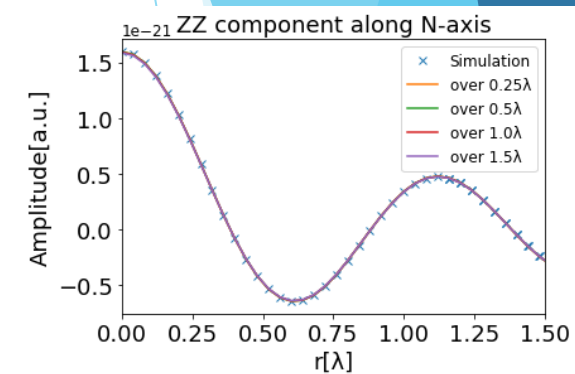
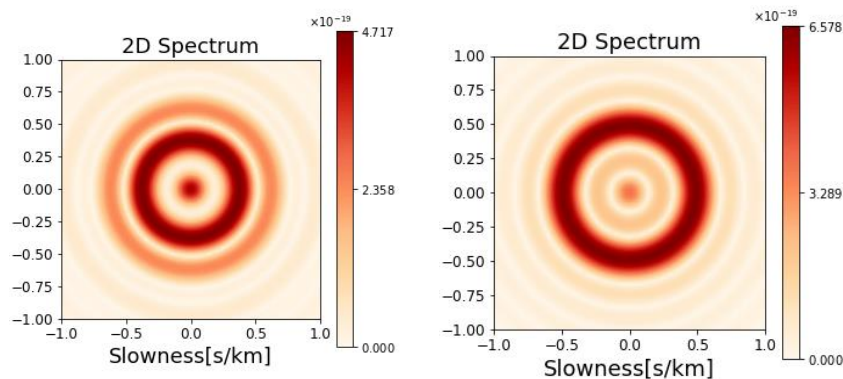
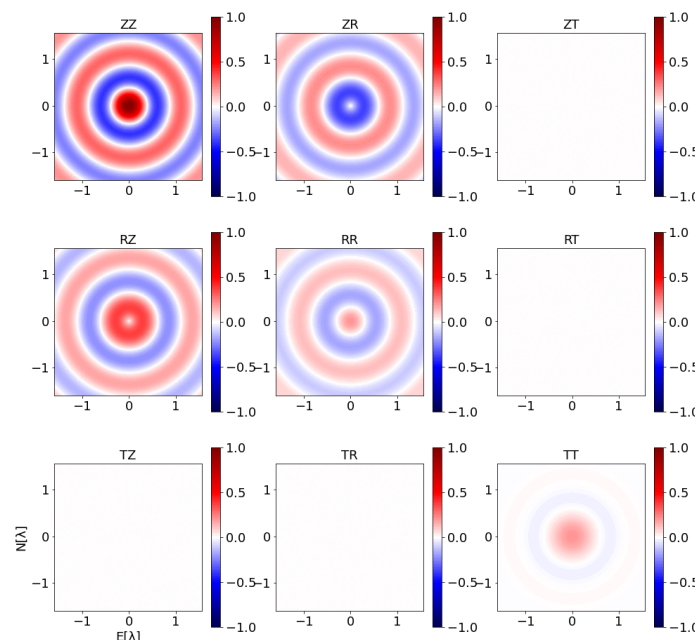
$$\phi_{ZR}(r, k(\theta)) = -AJ_1(k(\theta)r)$$

Apparent Rayleigh wavespeed
along azimuth θ

Homogeneous elastic half-space: estimating Rayleigh wave speed from near-field focal spot

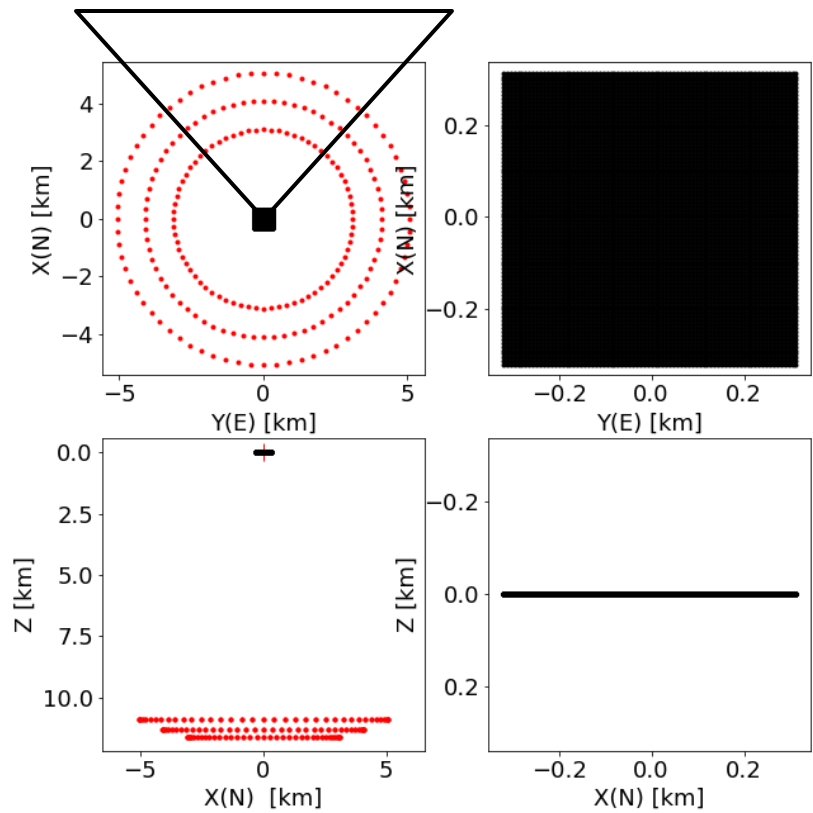


- Sampling rate: 50Hz
- Bandwidth 0-23 Hz
- 80x80 grid for stations with 8m interstation distance
- Rayleigh wave speed: 2000m/s
- $N=0$ for the fitting

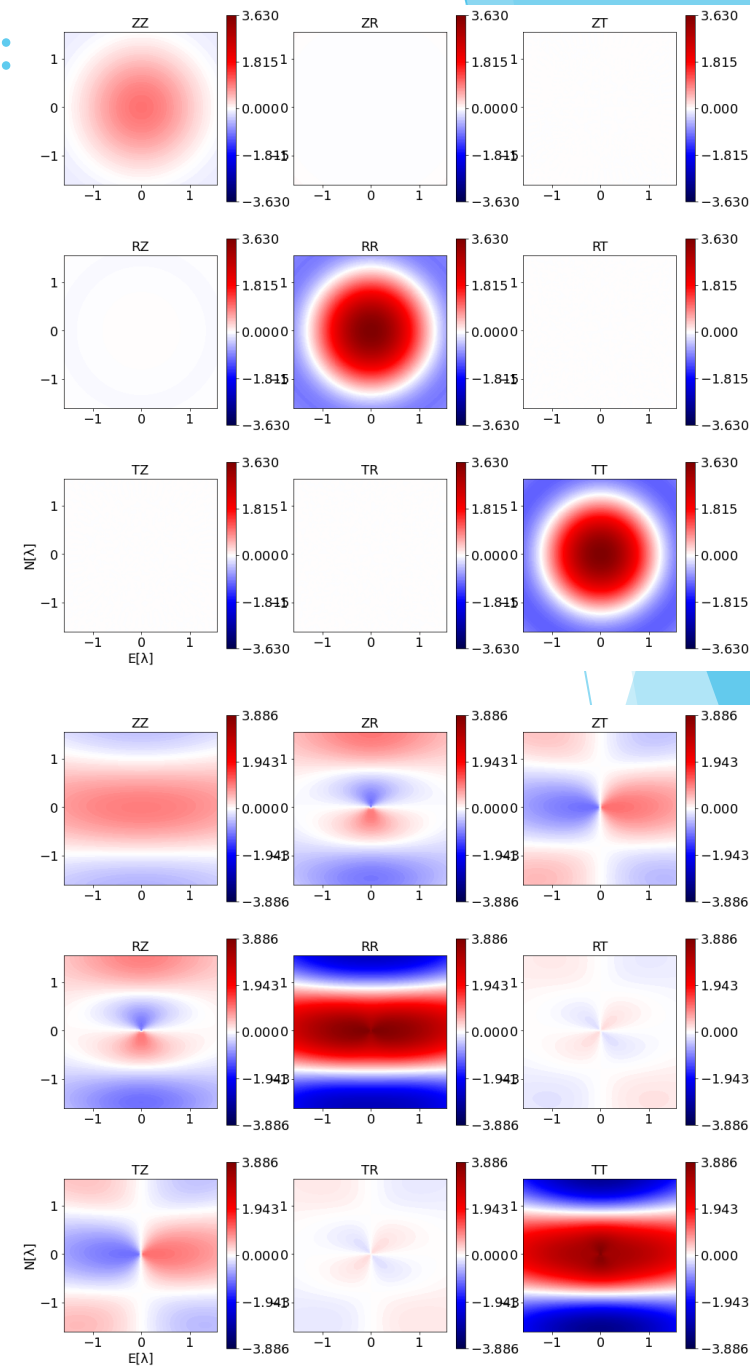


Feasibility of focal spot imaging in presence of P-waves: simulation

60 degrees sector

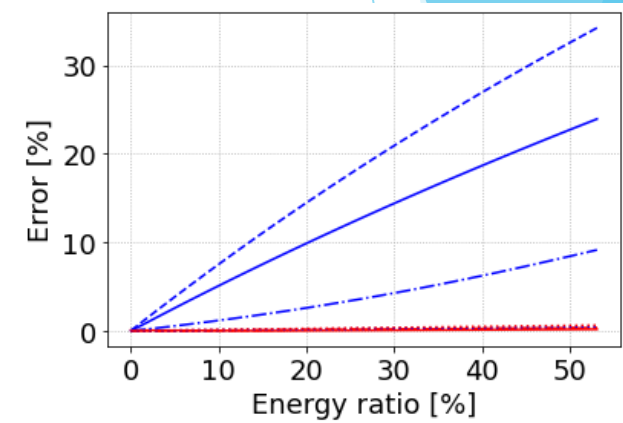
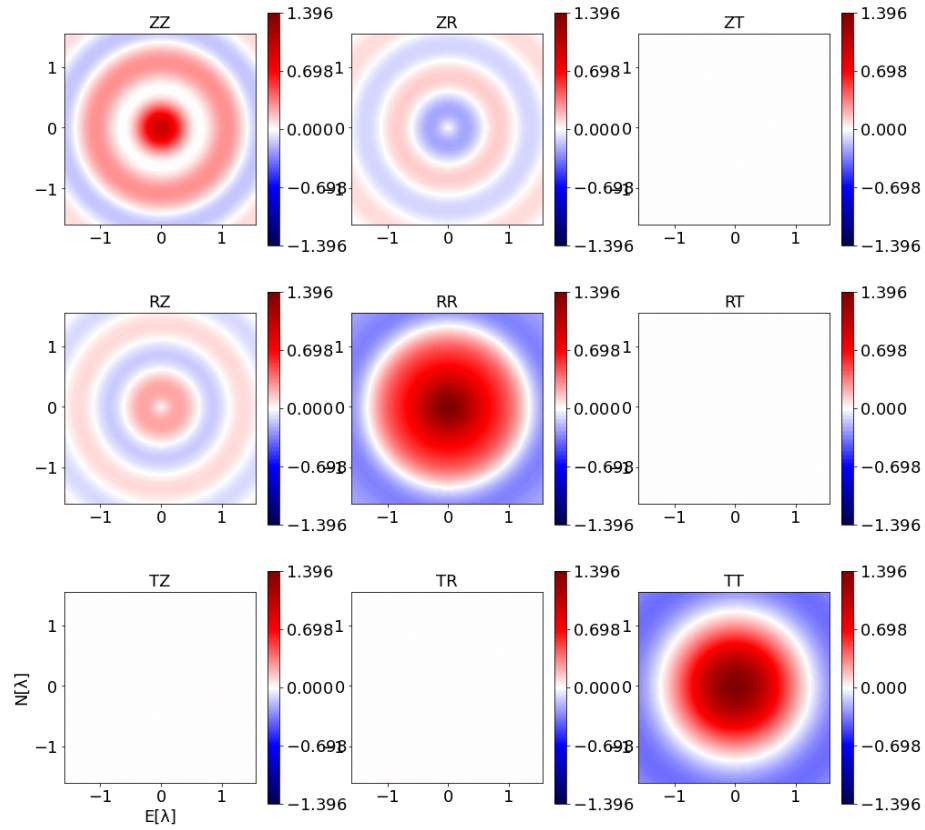


Simulation of P-waves and S-waves



Feasibility of focal spot imaging in presence of P-waves: distortion of focal spots

Isotropic distribution



ZZ: blue
ZR: red

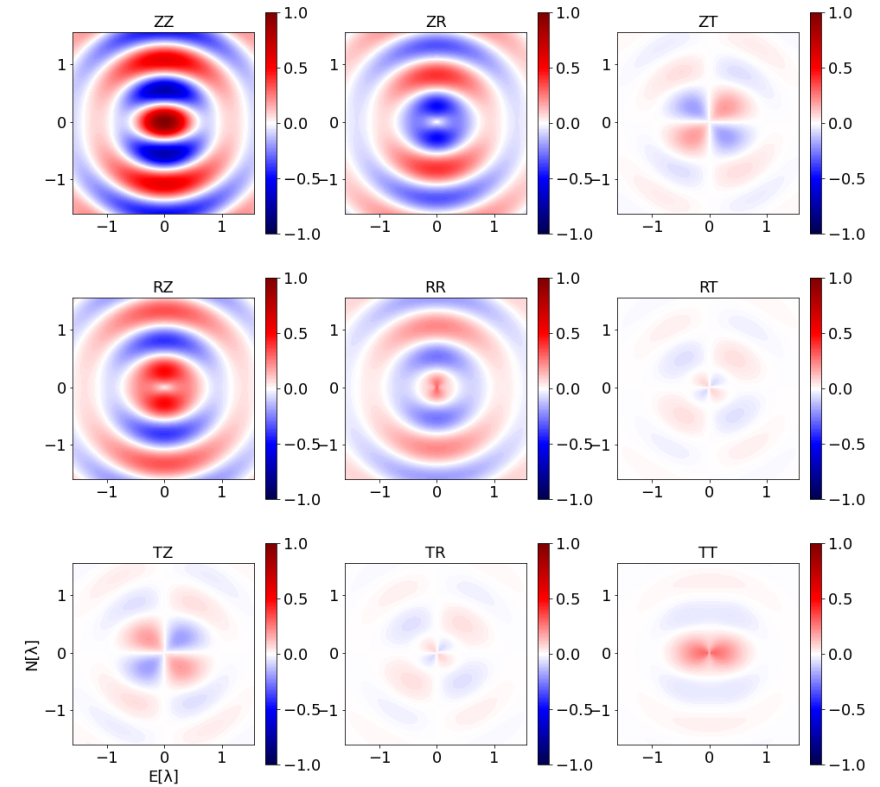
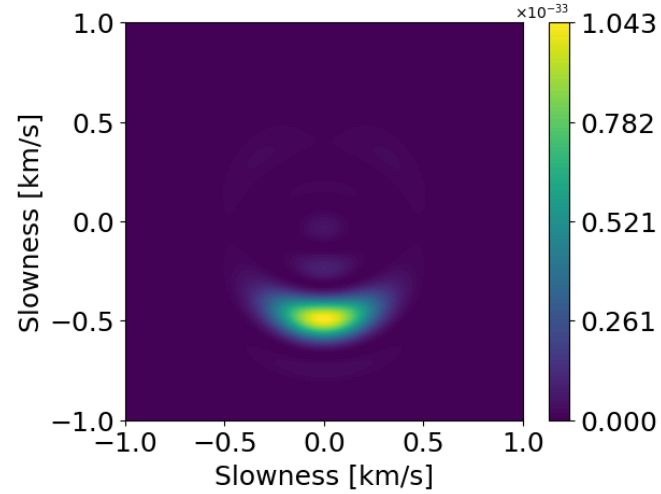
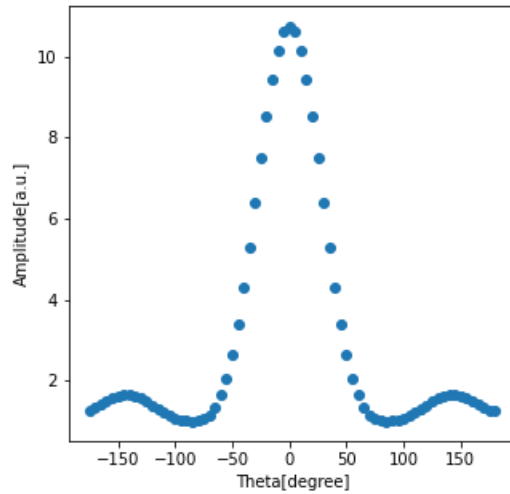
Presence of body waves: conclusion

- ZZ component is strongly impacted by body waves
- ZR component is more stable in most case if we use enough long distance for nonlinear regression (≥ 1 wavelength)

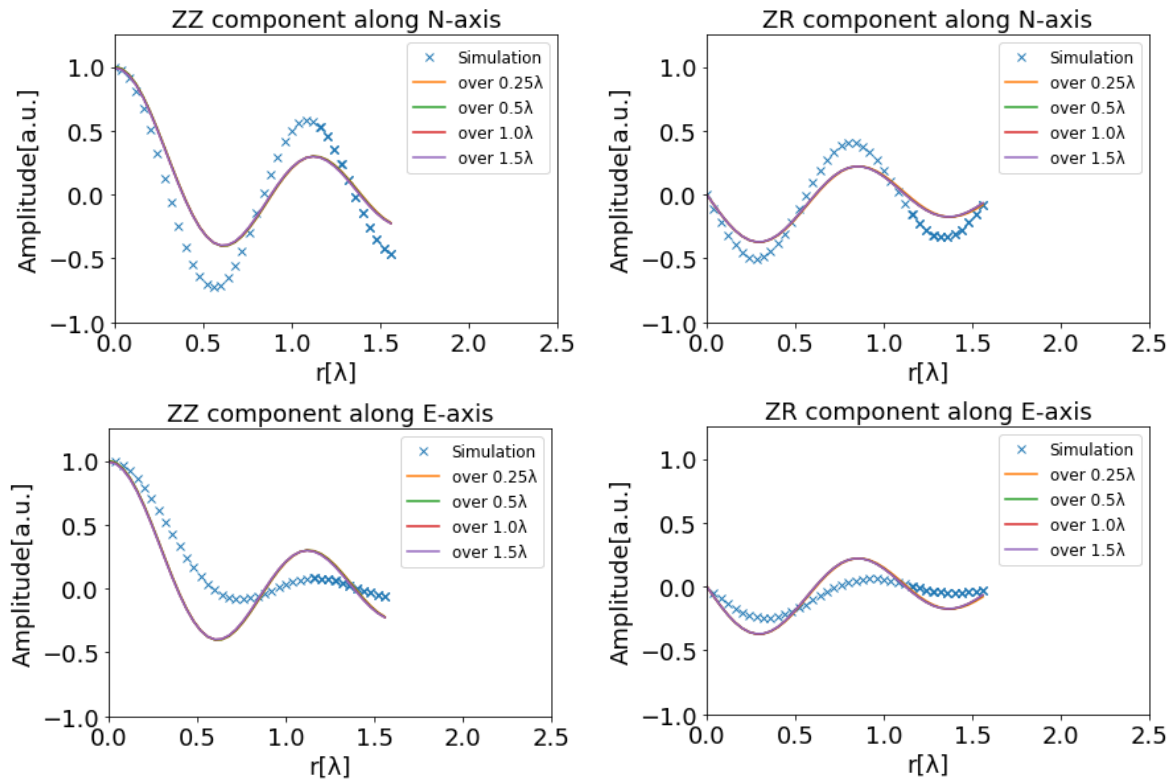


Presence of body waves would limit the resolution of the imaging method

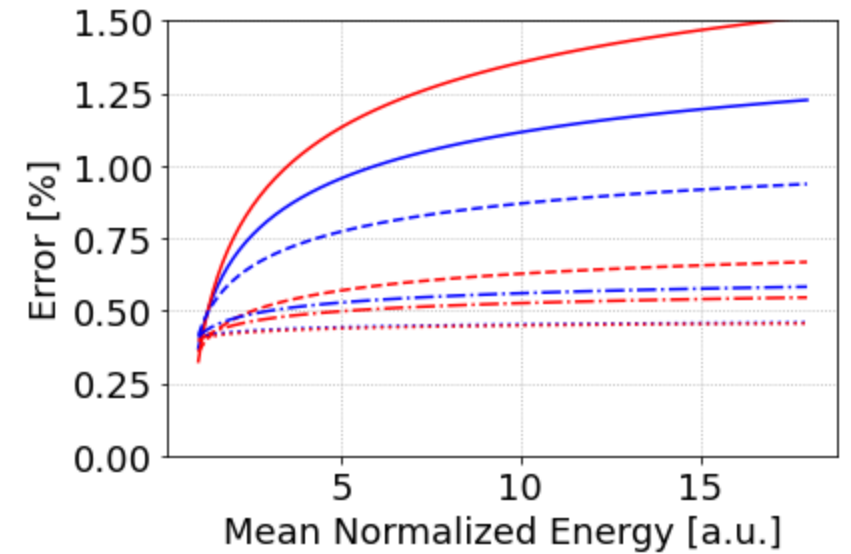
Anisotropic wave fluxes: example



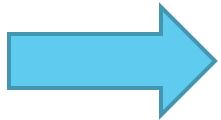
Isotropic wave number parameterization



ZZ: blue
ZR: red



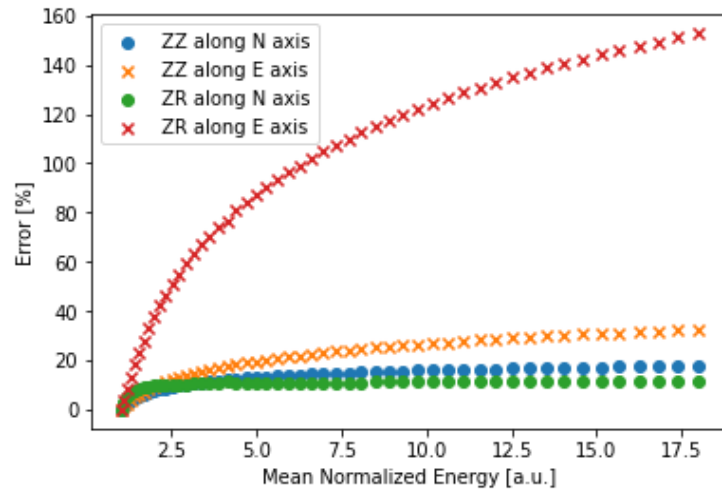
- Error is always small
- ZZ leads to higher error than ZR except for short distance



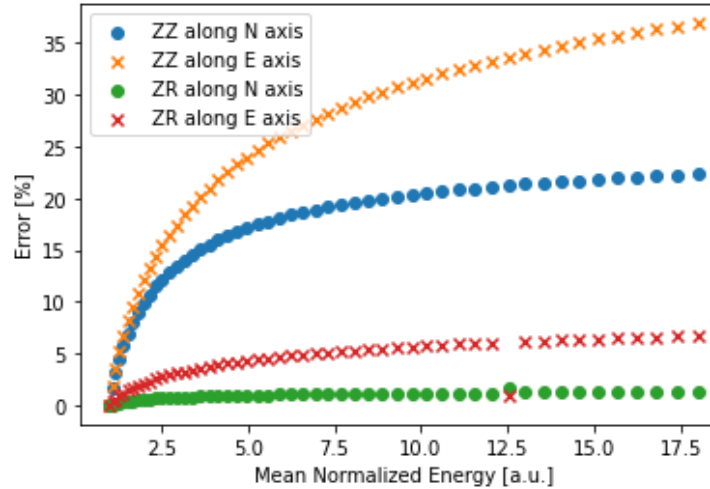
As for body waves, ZR component is a better choice for accuracy but it requires a trade-off about resolution

Azimuthal parametrization of the wave number

0.25λ

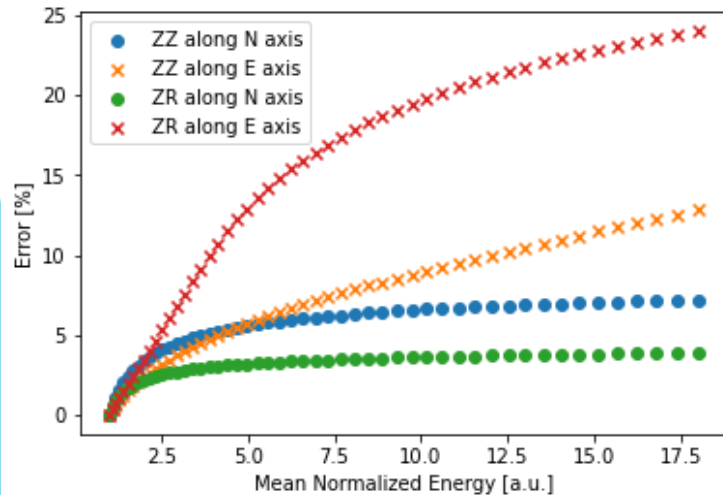


0.5λ

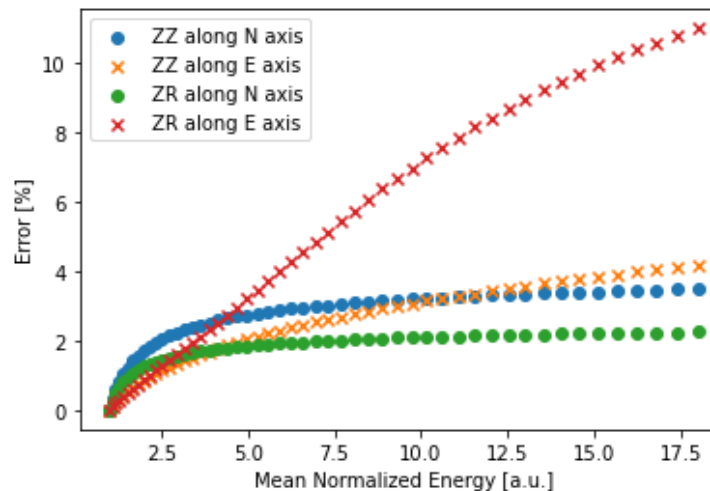


- Higher error on different direction
- ZR leads to higher error than ZZ

1λ

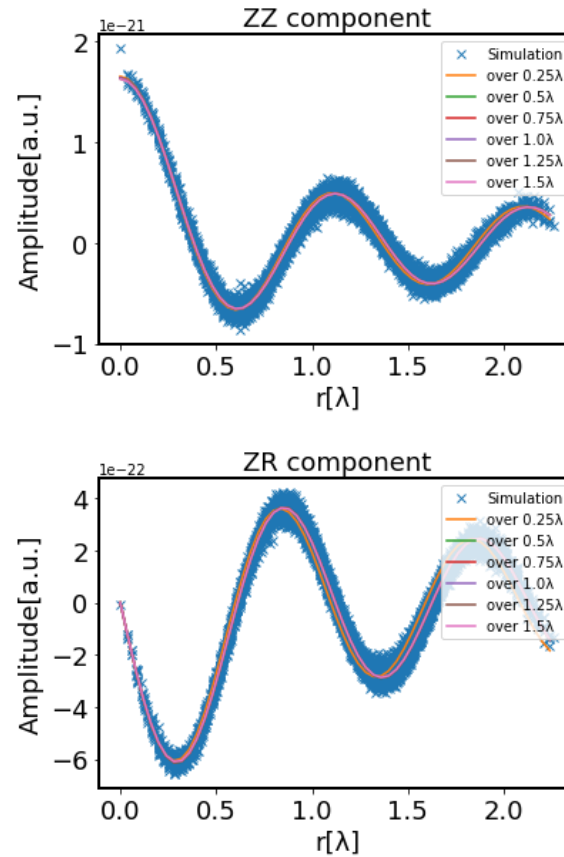
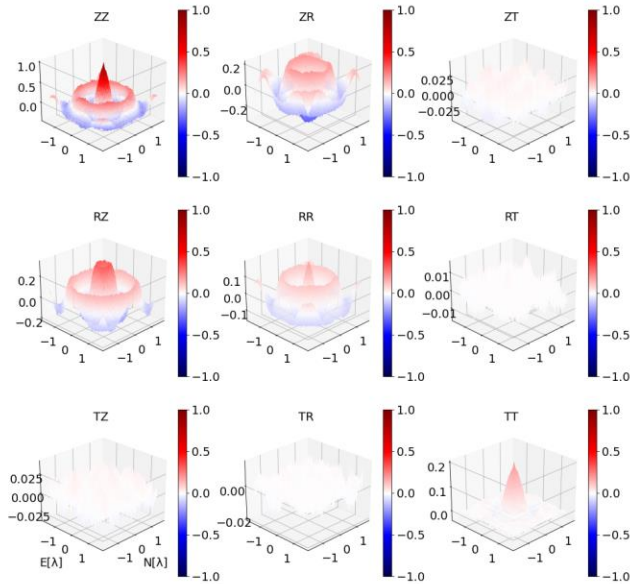


1.5λ

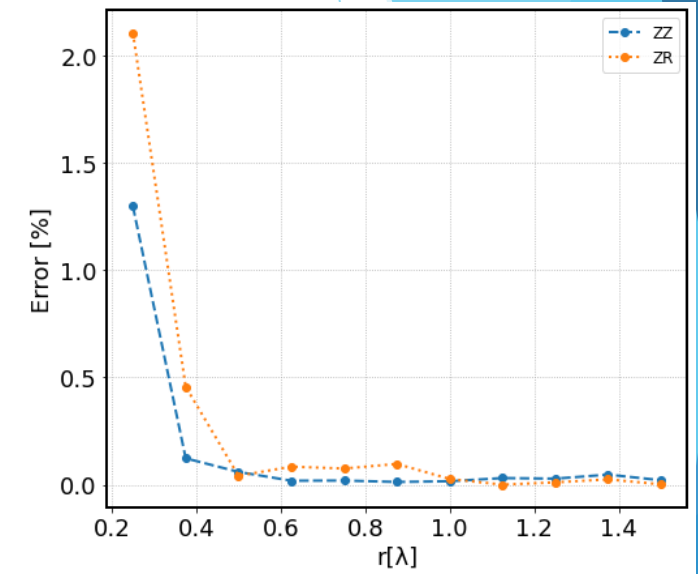


➡ To study anisotropy, ZR component is more impacted. However, all components present high error. Wave field needs to be isotropified.

Presence of noise (5% of variance)



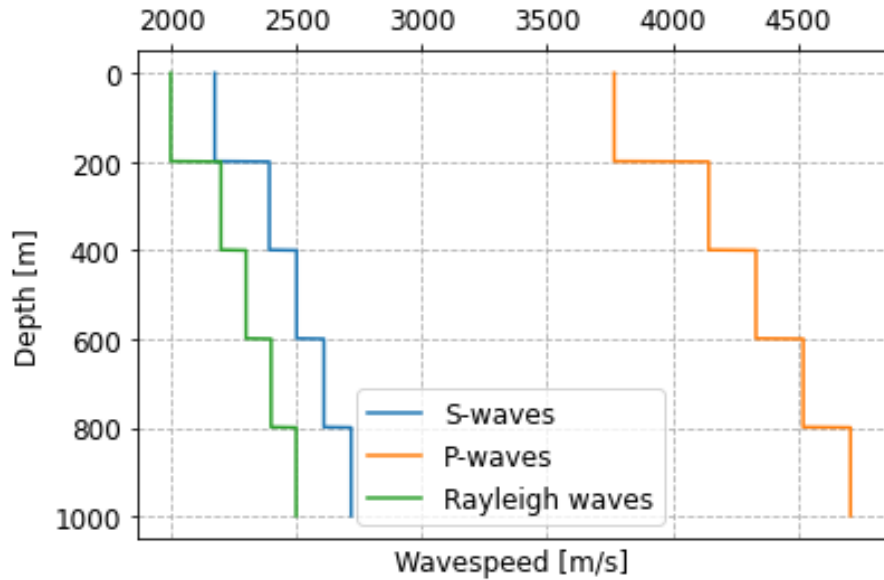
Estimation error in function of range used for nonlinear regression



Accurate fitting after 0.5 wavelength

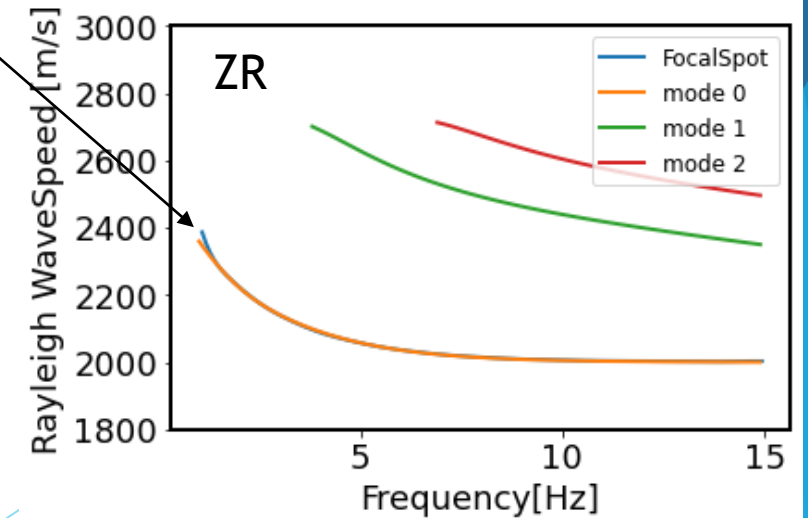
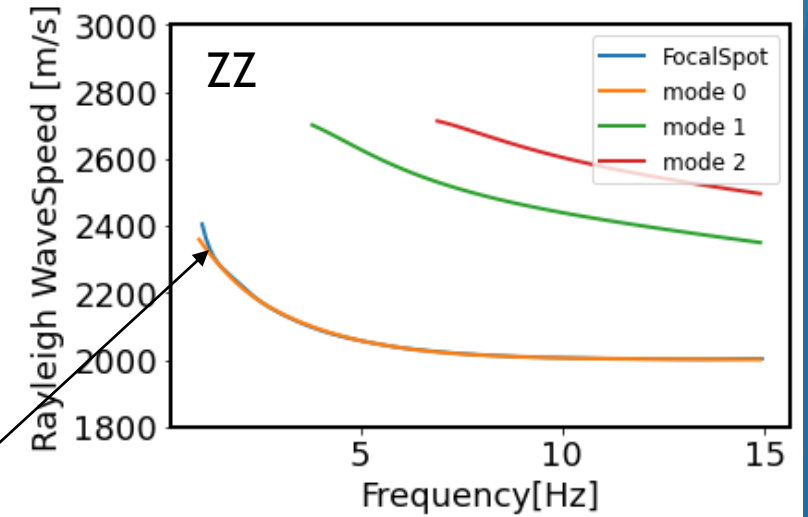
➡ Error on ZR component is higher in presence of noise

Dispersion

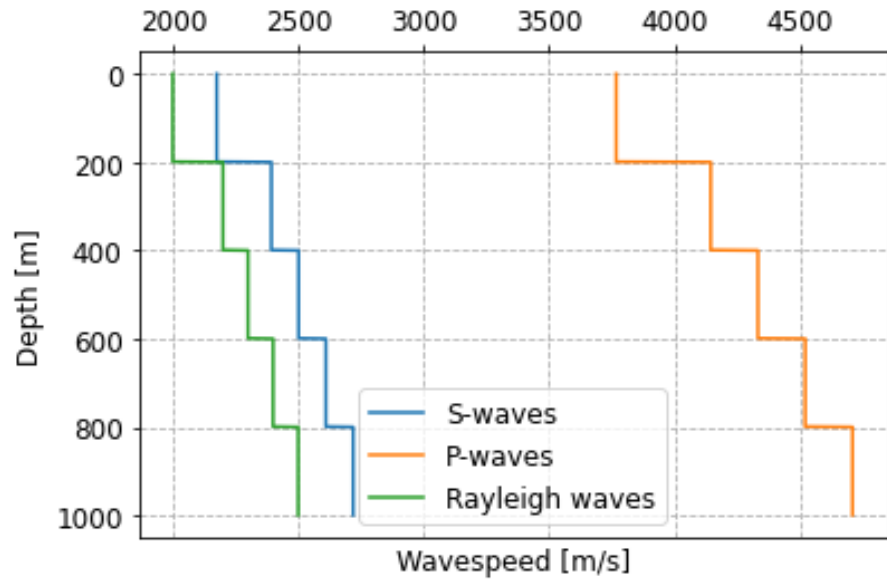


➡ Feasibility to retrieve dispersion using ZZ and ZR focal spots

Simulated focal spots VS
theoretical fundamental



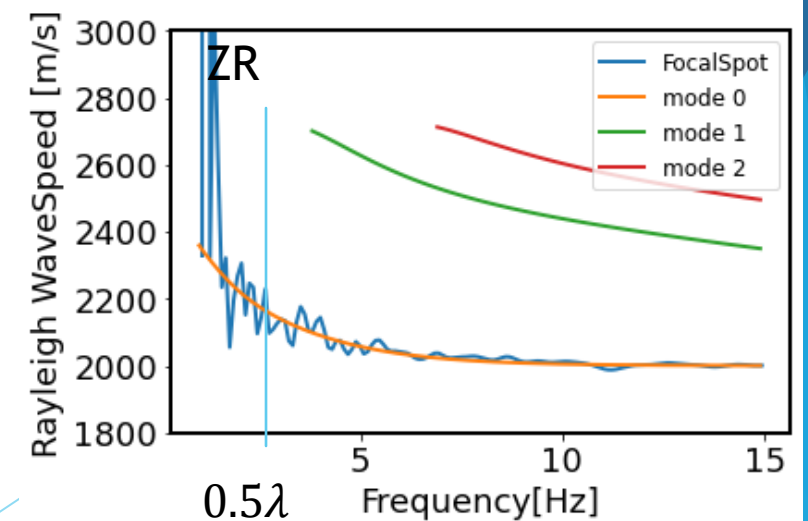
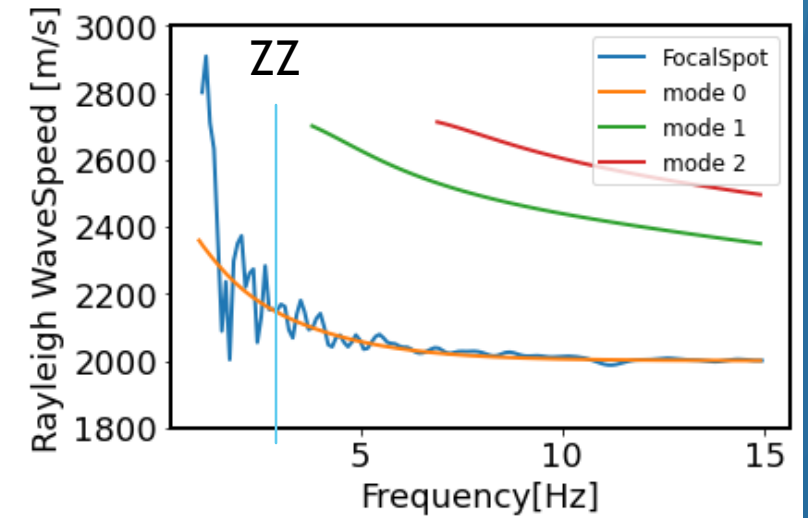
Dispersion (noise 5% of variance)



More noise on low frequencies

➡ Agreement with previous noise results

➡ ZR component is also less stable at the lowest frequencies



Conclusion

- ▶ Without filtering, around 1 wavelength should be used for fitting
- ▶ To study anisotropy, the wave fluxes needs to be isotropified
- ▶ ZR leads to better estimation in case of body waves and anisotropic wave fluxes
- ▶ ZZ is better in presence of noise.



The choice of the used component should depend on the filtering method that are used.