Time reversal in a heterogeneous solid half-spaces

Yingzi Ying†, Chris Bean and Ivan Lokmer
†yingzi.ying@ucd.ie
Seismology Laboratory, School of Geological Sciences, University College Dublin, Dublin, Ireland

Introduction

- About time reversal
  - Time reversal is a technique to refocus waves based upon the reciprocity of wave equation by reversely playing back signals [Fink and Prada, 2001].
- Motivation
  - Investigation of the time reversal refocusing properties in heterogeneous solid half-spaces, which has been demonstrated to exhibit super-resolution in inhomogeneous fluids [Borcea et al., 2003] and is statistical stable [Papanicolaou et al., 2004].
- Methodology
  - Numerical simulations using spectral element method [Tromp et al., 2008].

Simulation configurations

- Configurations:
  - A cross time reversal mirror is deployed on the free surface.
  - An isotropic explosive source emanating **50** Hz Ricker wavelet is directly below the array at **1000** m depth.
  - Three isotropic heterogeneous solid media are created, in which the P-wave velocity structures are characterized by Gaussian, exponential and von Kármán (Hurst number $\nu = \mathbf{0.2}$) power spectral density functions, respectively [Sato et al., 2012]. The standard deviation is 10**%** of the mean value (**3500** m/s), and the correlation length equals to the dominant P-wavelength (**70** m). S-wave velocity and density are set as $v_s = v_p/\sqrt{3}$ and $\rho = \mathbf{2400}$ kg/m^3, respectively.

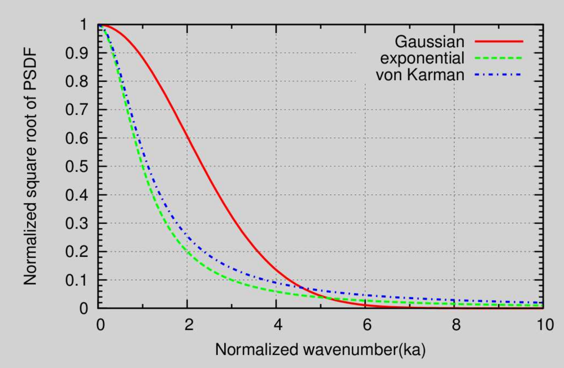


Fig. 1: Filters to generate isotropic heterogeneous media.

Homogeneous | Gaussian | Exponential | von Kármán

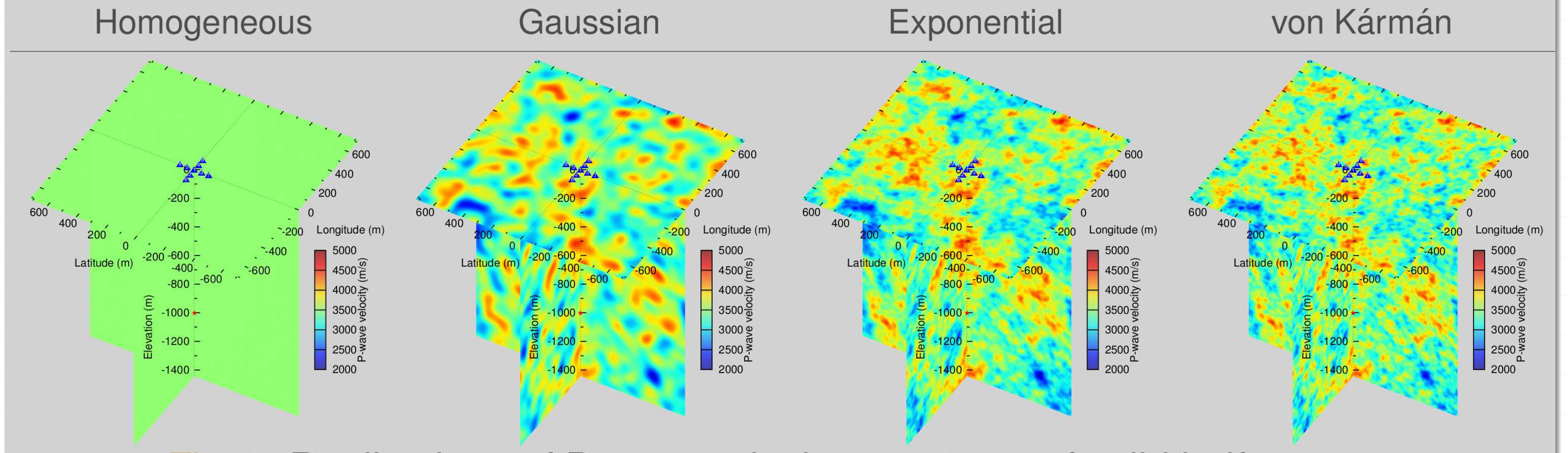
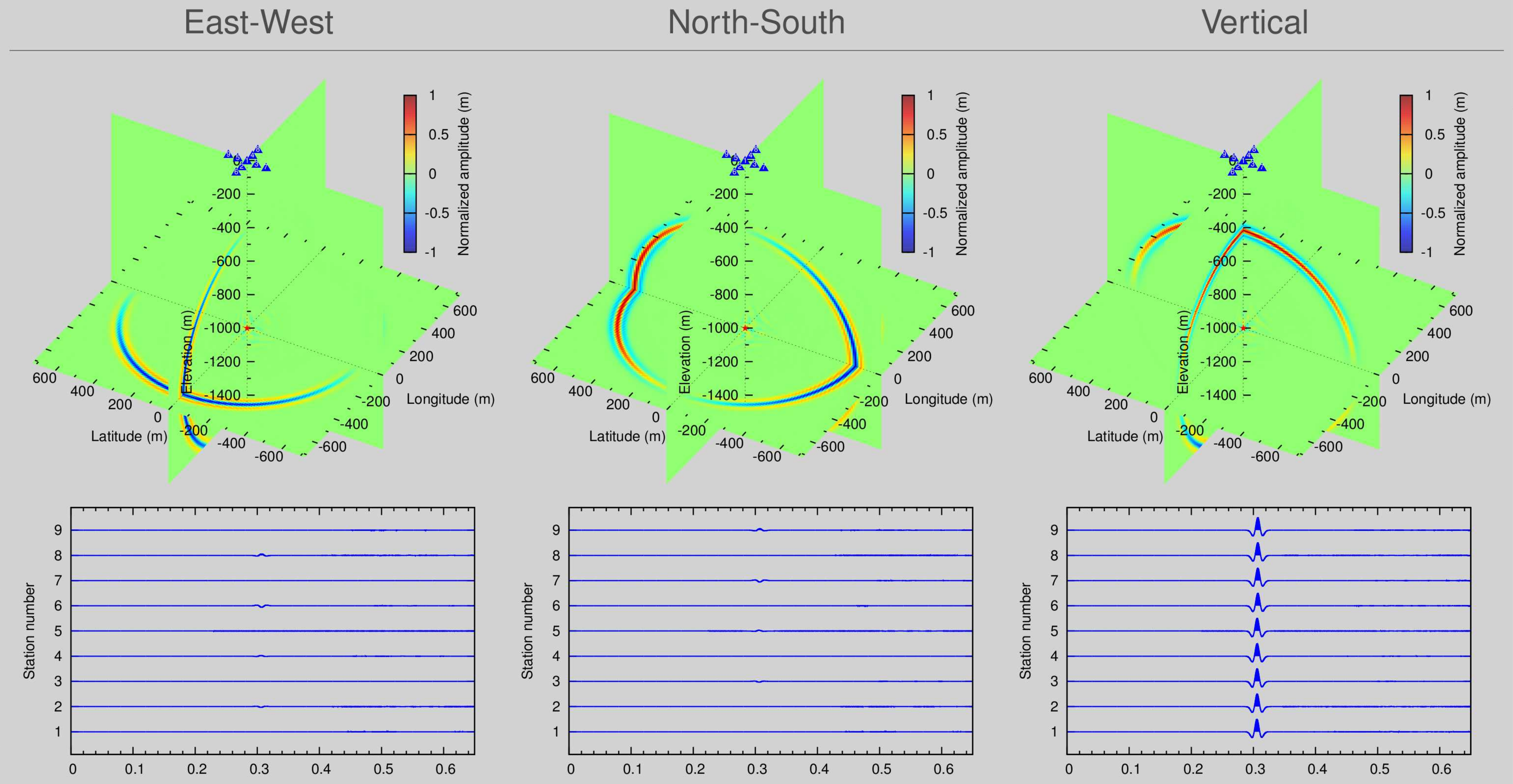


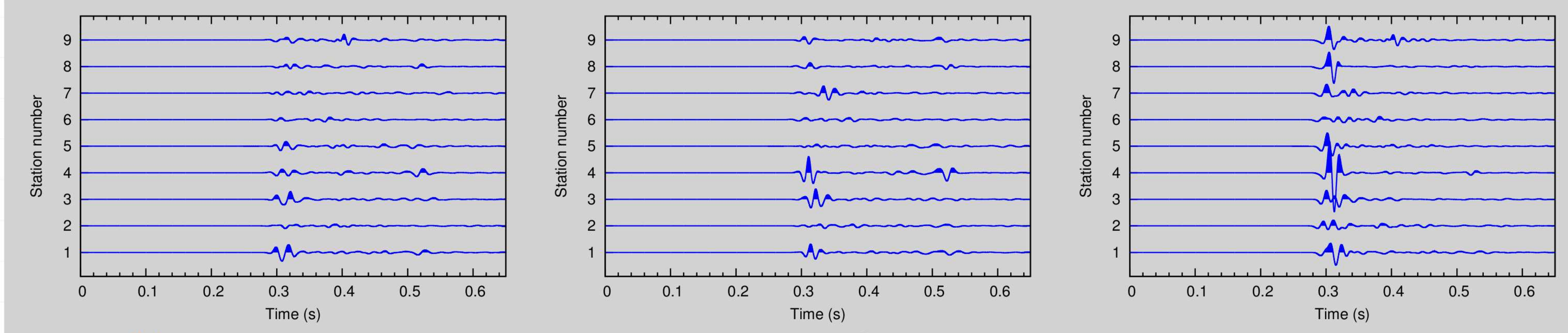
Fig. 2: Realizations of P-wave velocity structures of solid half-spaces.

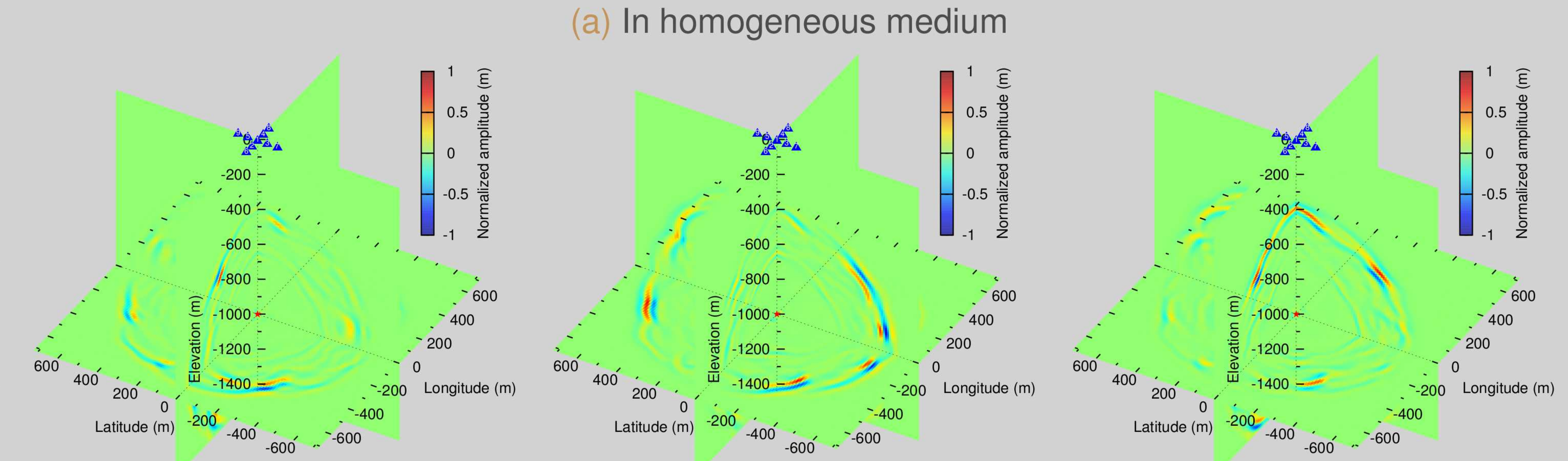
Seismic wave propagation in heterogeneous solid half-spaces

East-West | North-South | Vertical

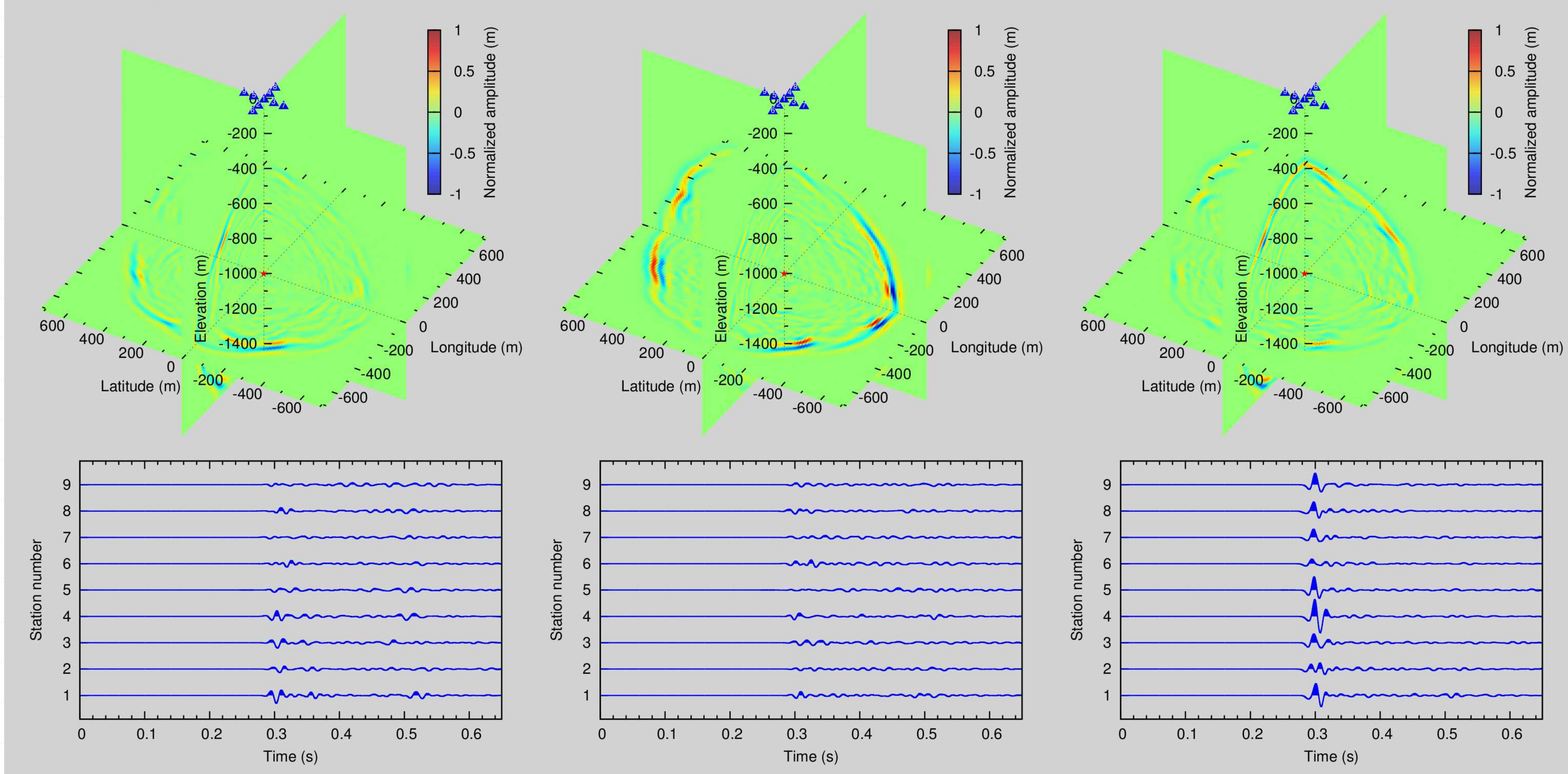


(a) In homogeneous medium

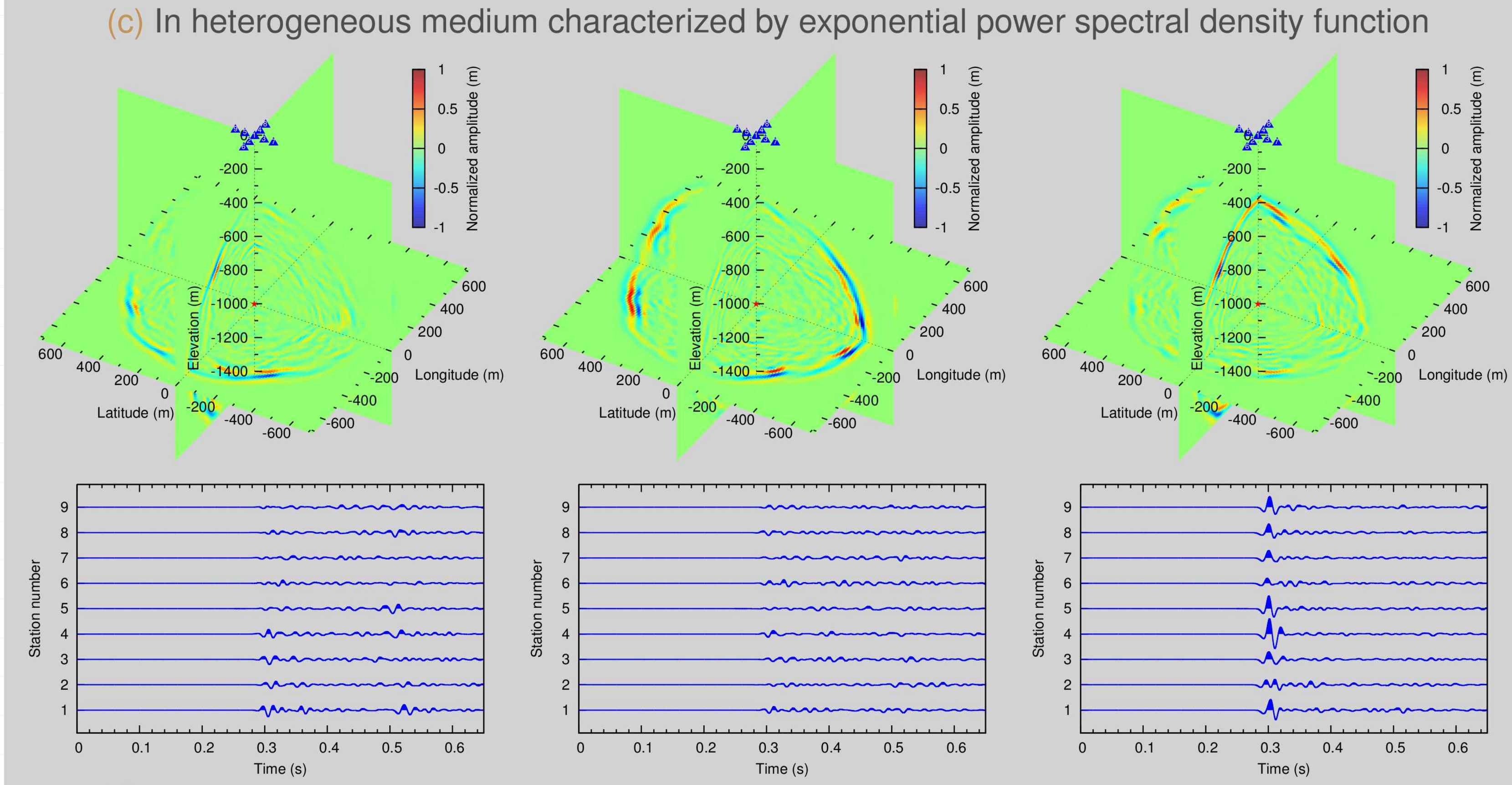




(b) In heterogeneous medium characterized by Gaussian power spectral density function



(c) In heterogeneous medium characterized by exponential power spectral density function

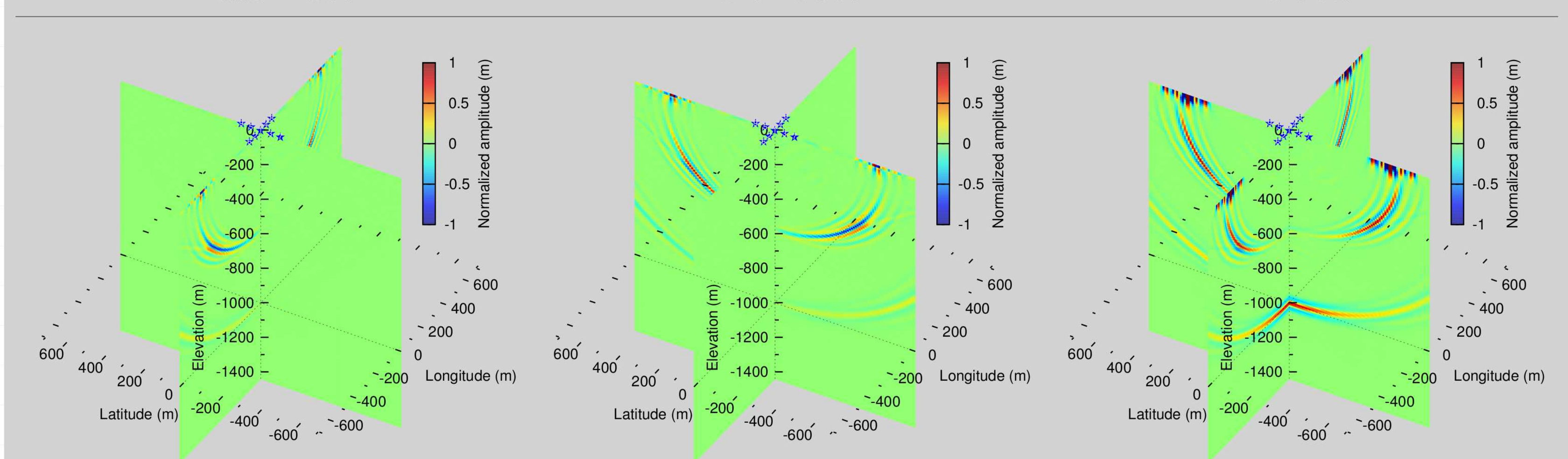


(d) In heterogeneous medium characterized by von Kármán power spectral density function

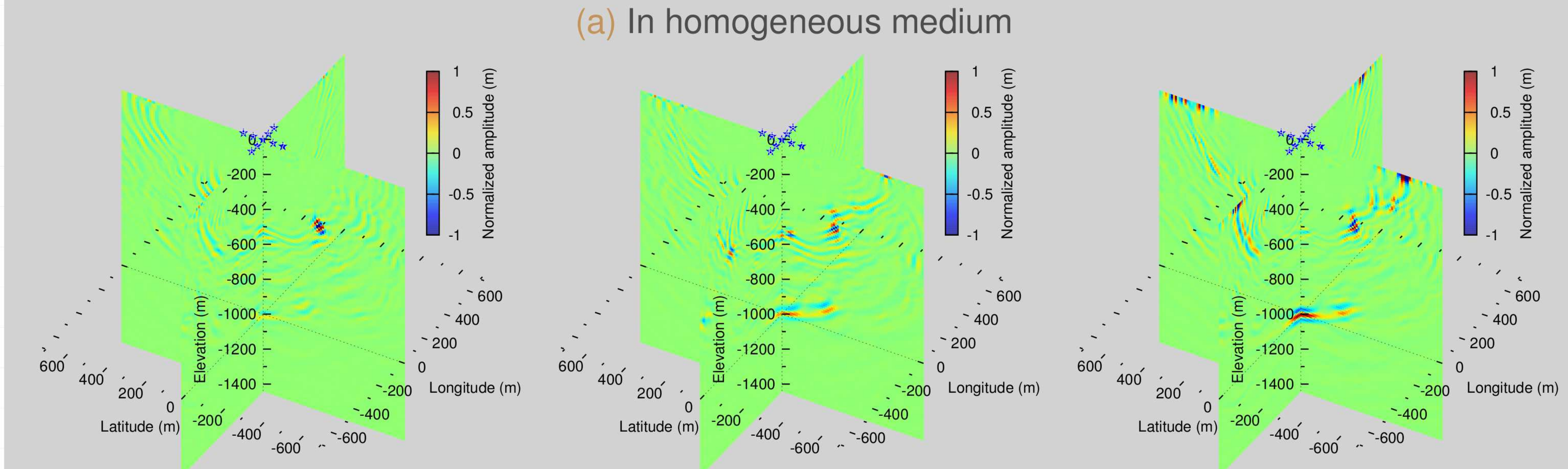
Fig. 3: Forward displacement wavefield snapshots and traces.

Time reversal refocusing in heterogeneous solid half-spaces

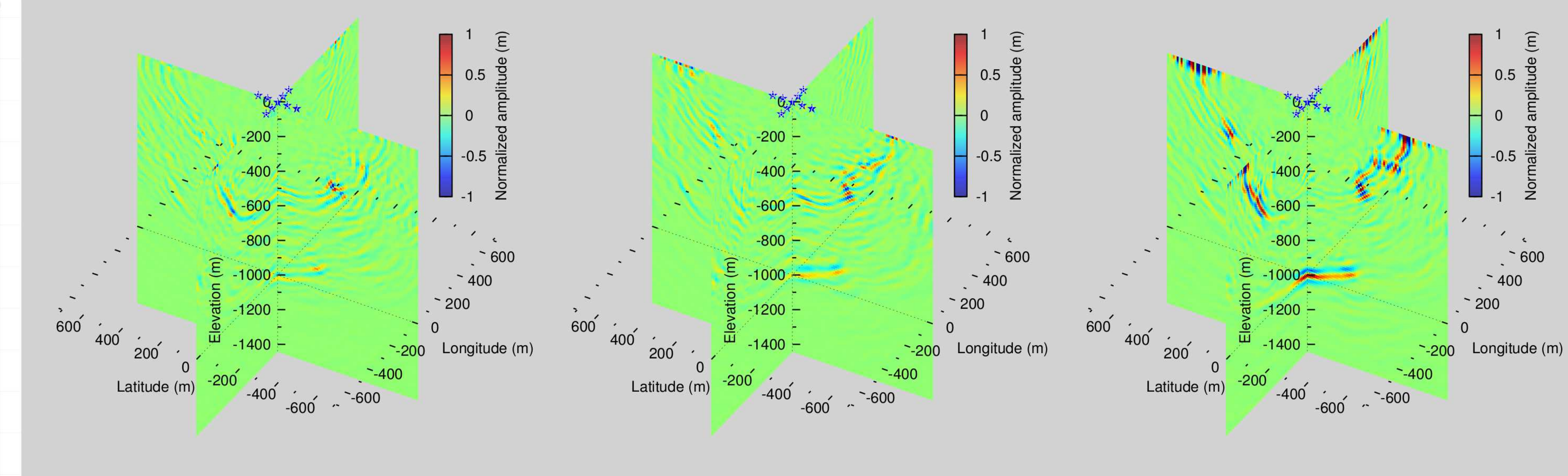
East-West | North-South | Vertical



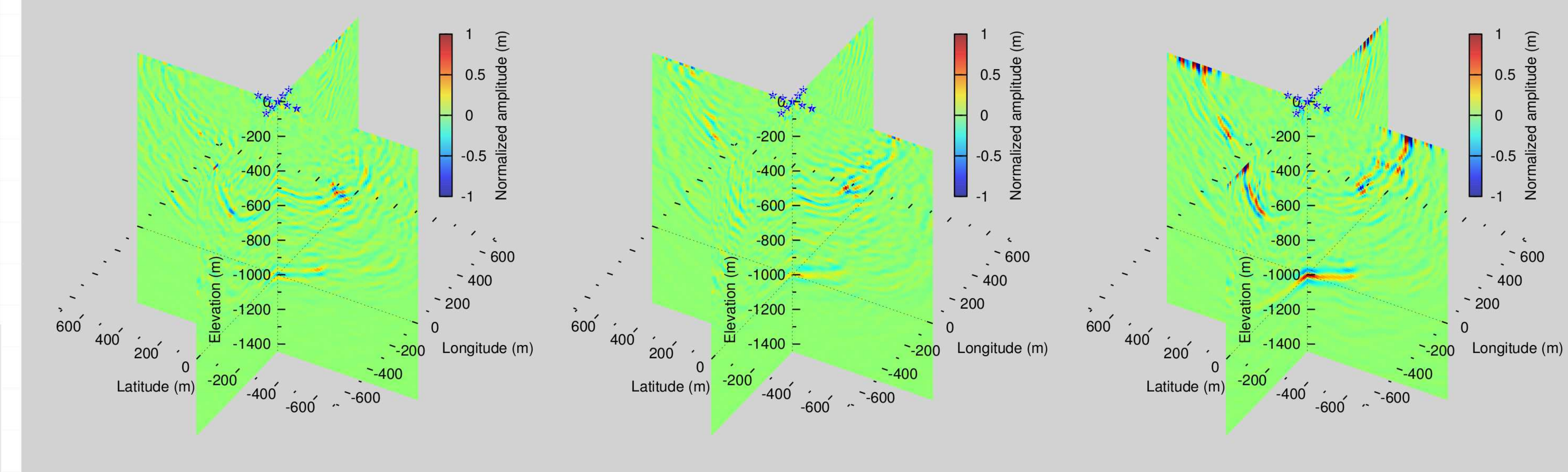
(a) In homogeneous medium



(b) In heterogeneous medium characterized by Gaussian power spectral density function



(c) In heterogeneous medium characterized by exponential power spectral density function



(d) In heterogeneous medium characterized by von Kármán power spectral density function

Fig. 4: Backward displacement wavefield snapshots at refocusing time.

Note: (i) Refocusing can only be observed in the vertical displacement wavefields here. (ii) The snapshots are normalized by the respective focal peak values of vertical displacement wavefields.

East-West | North-South | Vertical

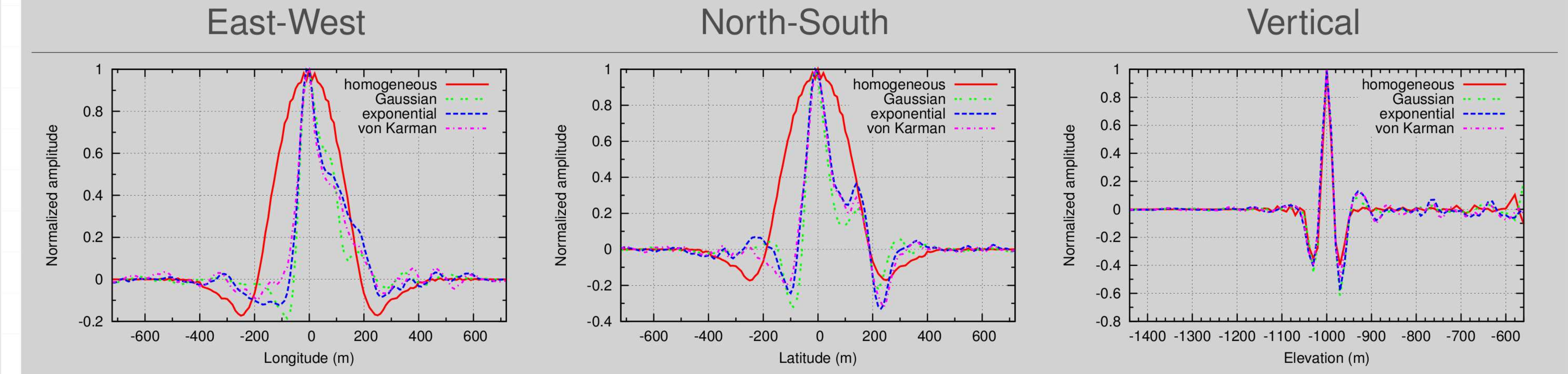


Fig. 5: Comparision of on-axis vertical displacements.

Summary

- Playing back the time reversed 3-component displacements on the top free surface excites surface waves, which are the most energetic of transmitted waves.
- The lateral refocusing becomes much better in heterogeneous solid media than in the homogeneous one, which is caused by multi-pathing and multiple scattering due to the inhomogeneities. Also, the refocusing is independent of particular realizations of random media, that is because the time reversal fields is self-averaging in heterogeneous solids.
- The radial resolution is not enhanced.

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