Empirical radiation patterns as a method to assess crosstalk under scenarios of heterogeneous reference media

Mariana Lume*, Ivan J. Sánchez G. and Kris Innanen
mariana.lume@ucalgary.ca

Abstract

Analysis of radiation patterns is a common method to evaluate parameter crosstalk in FWI. Typically, these are constructed from analytic expressions subject to homogeneous reference media. This study introduces a workflow to extract empirical radiation patterns from scattered wavefields and we apply it to assess the Vp, Vs and ρ patterns produced under heterogeneous backgrounds. To achieve this, radius dependent masks and sweeps of angles were used. The proposed workflow extracts accurate empirical patterns and shows that, under heterogeneous scenarios, the shape of the radiation patterns changes from what is theoretically expected, generating slightly different crosstalk regions as well as sensitivity variations.

Analytic Vp, Vs and ρ radiation patterns

The medium where a wave propagates is the sum of a homogeneous background and small model perturbations. To extract the analytic radiation patterns of a scattered wavefield, we can analyze a plane wave that interacts with a scatter point (Figure 1) using the Born approximation.

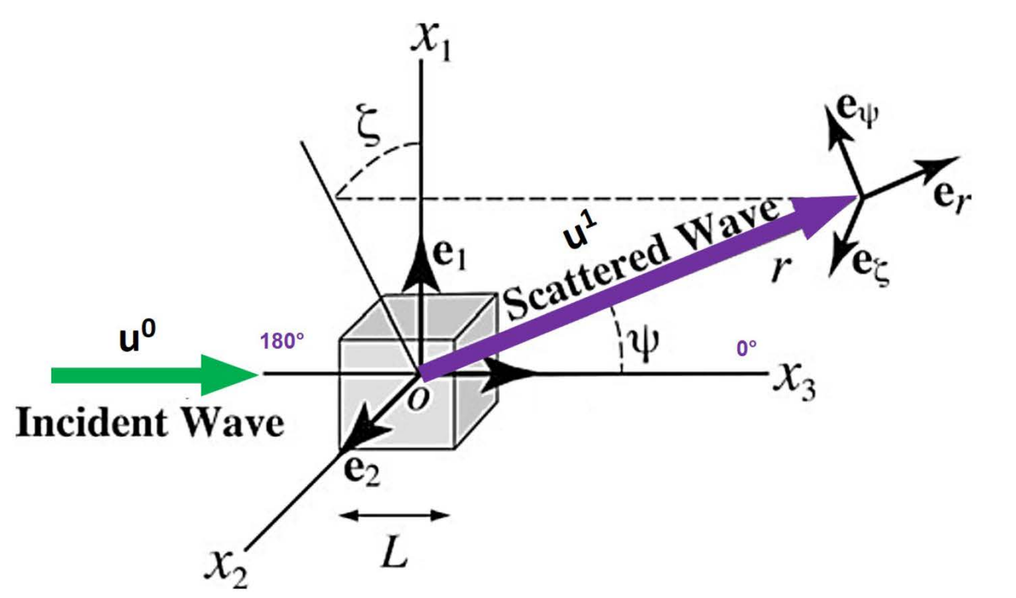

Figure 1. Scatter point of size L; r, Ψ and ζ are spherical coordinates and e_r, e_Ψ and e_ζ are the unit base vectors in that system (Modified from Sato et al. (2012)).

Sato et al., (2012) demonstrate that the analytic expressions come after considering: $\mathbf{u} = \mathbf{u}^0 + \mathbf{u}^1$, the isotropic elastic wave equation in time domain for the full displacement wavefield $\mathbf{u}(\mathbf{x}; t)$, Green's function to solve for the desired type of scattered waves and the transformation of the scattering amplitudes to spherical coordinates, obtaining:

$$RP_{\rho_r}^{PP} = \frac{1}{\gamma_0^2}\left(-1 + \cos\Psi + \frac{2}{\gamma_0^2}(\sin\Psi)^2\right)$$

$$RP_{Vp_r}^{PP} = \frac{2}{\gamma_0^2}$$

$$RP_{Vs_r}^{PP} = \frac{4}{\gamma_0^4}(\sin\Psi)^2$$

$$RP_{\rho_\Psi}^{PS} = -\sin\Psi + \frac{2}{\gamma_0}\cos\Psi\sin\Psi$$

$$RP_{Vs_\Psi}^{PS} = \frac{4}{\gamma_0}\cos\Psi\sin\Psi$$

Extraction of empirical radiation patterns

Scattered wavefields (Figure 2) were simulated under homogeneous reference media with a 10% increase for the scatter point value, in one of the three parameters. Vertical (u_z) and horizontal (u_x) displacement wavefields were recorded.

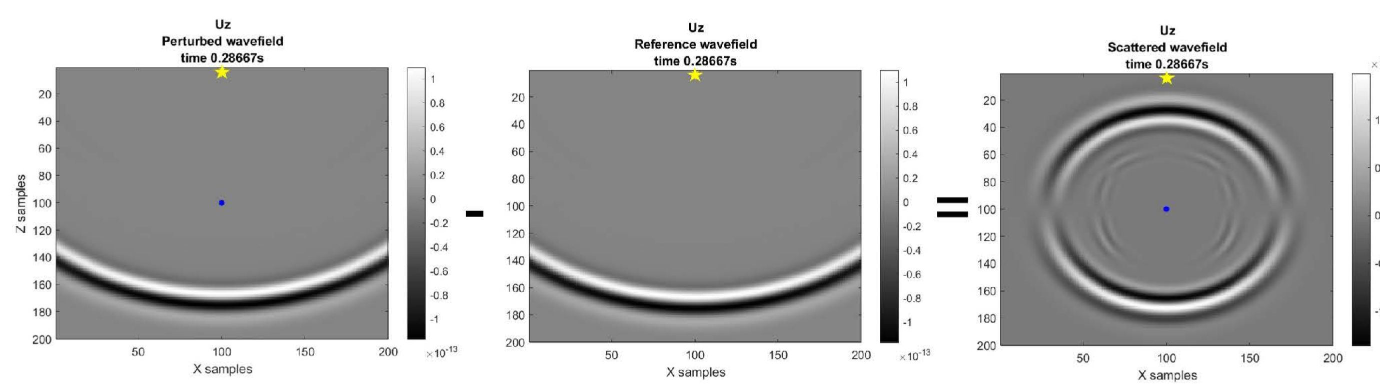

Figure 2. Scattered wavefield. The blue dot is the scatter point, while the yellow star represents the explosive source.

Radius dependent masks isolated the P-P and P-S wavefields. Energies of u_x and u_z were measured in a sweep of angles defined by a reference angle. Equation $|\boldsymbol{u}^1| = \sqrt{u_x^2 + u_z^2}$ was applied and this amplitude was assigned to the corresponding reference angle (Figure 3). Empirical radiation patterns were extracted (Figure 4).

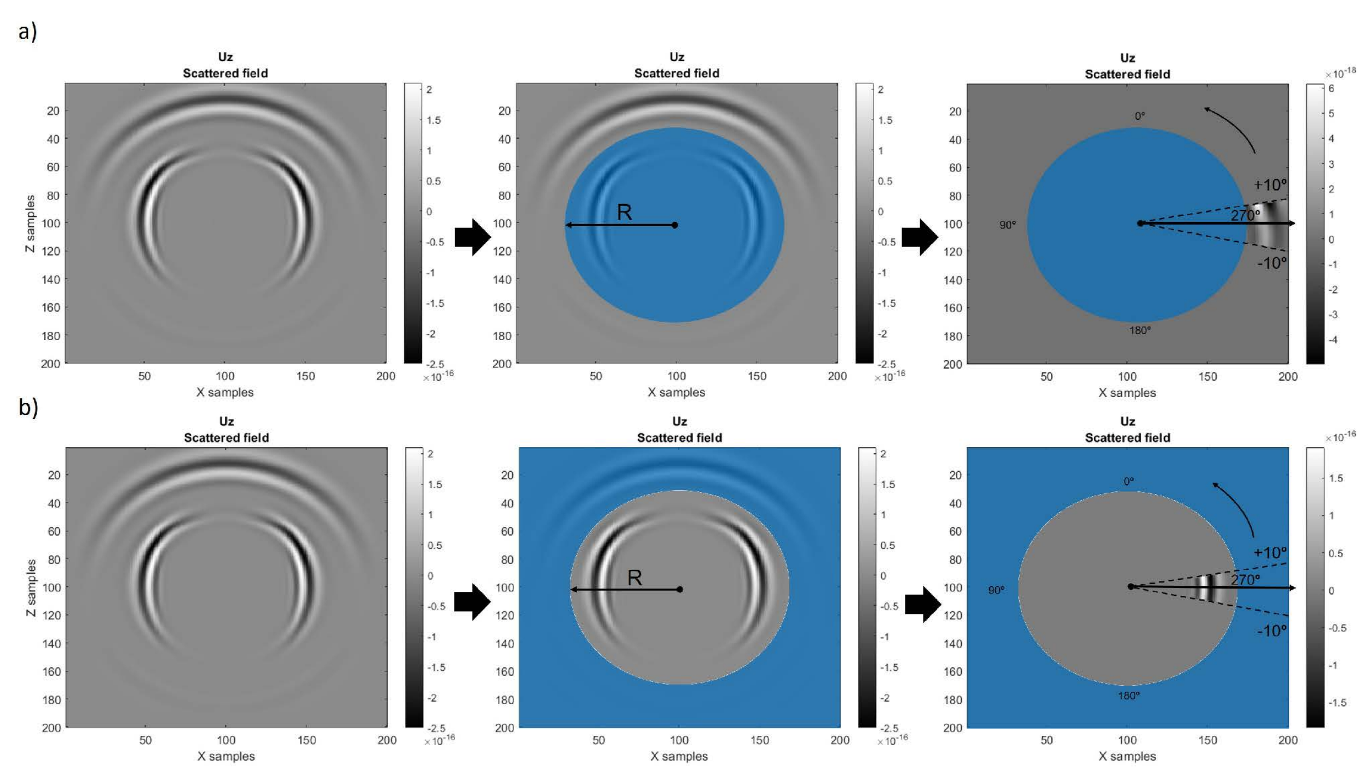

Figure 3. Proposed workflow. (a) Extraction of P-P patterns and (b) of P-S patterns. R is the radius of the mask.

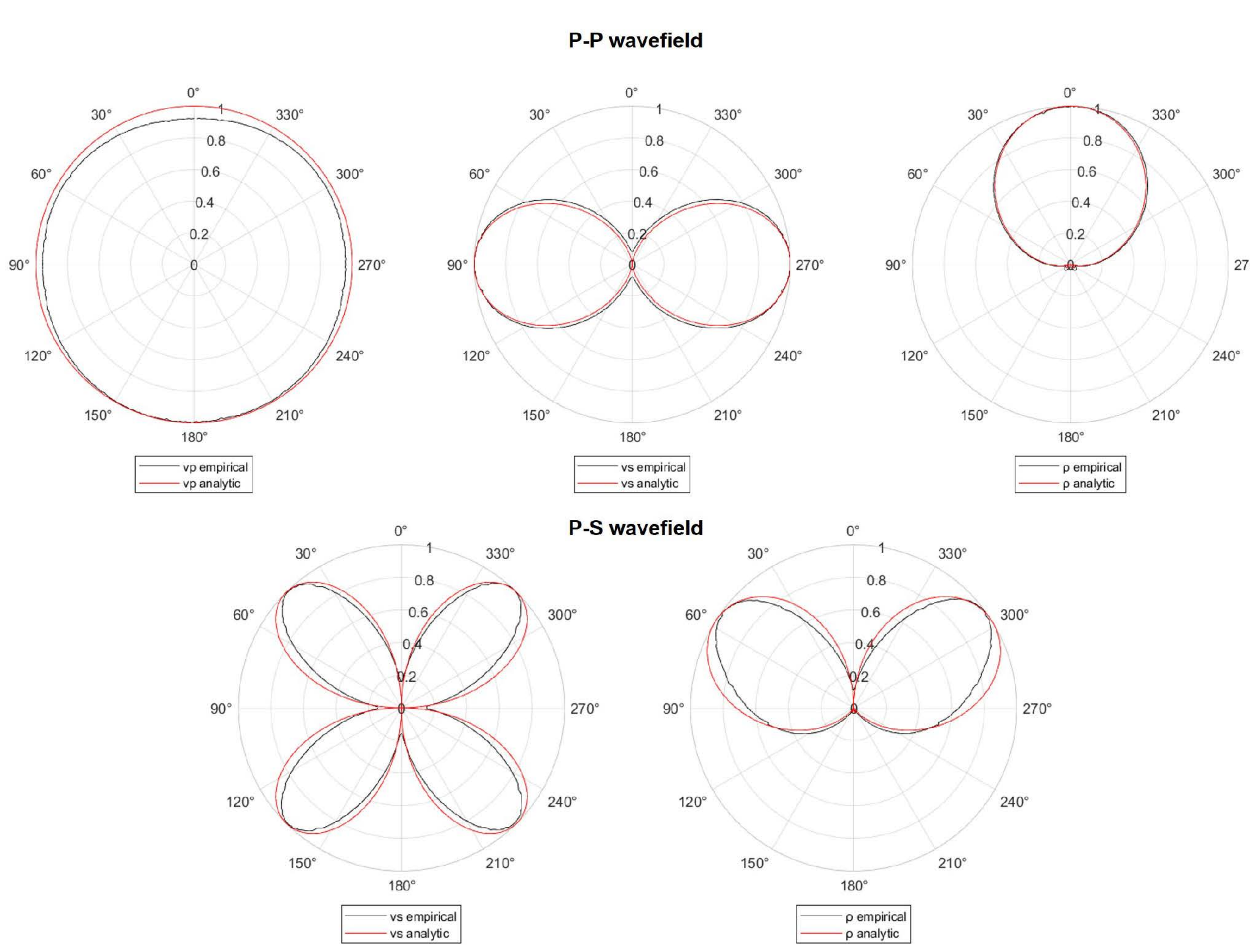

Figure 4. Comparison of analytic and empirical radiation patterns of P-P and P-S wavefields.

Radiation patterns with heterogeneous reference media

Different heterogeneous backgrounds were considered (Figure 5). Empirical radiation patterns for each of them were extracted using the proposed workflow (Figure 6).

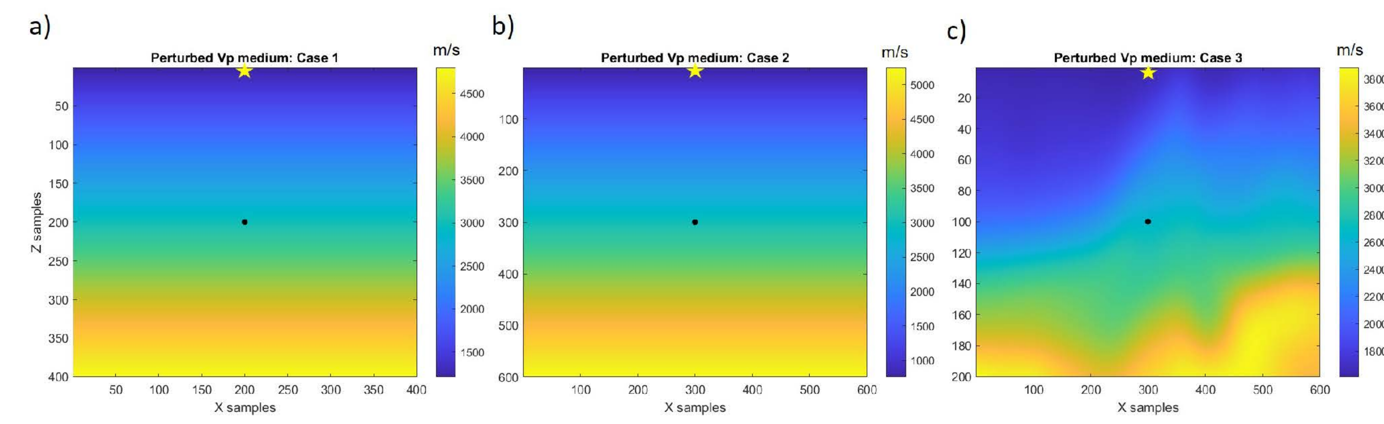

Figure 5. (a) case 1: linear change with depth; (b) case 2: linear change with depth, with 25% increment of the slopes; (c) case 3: modified Marmousi model.

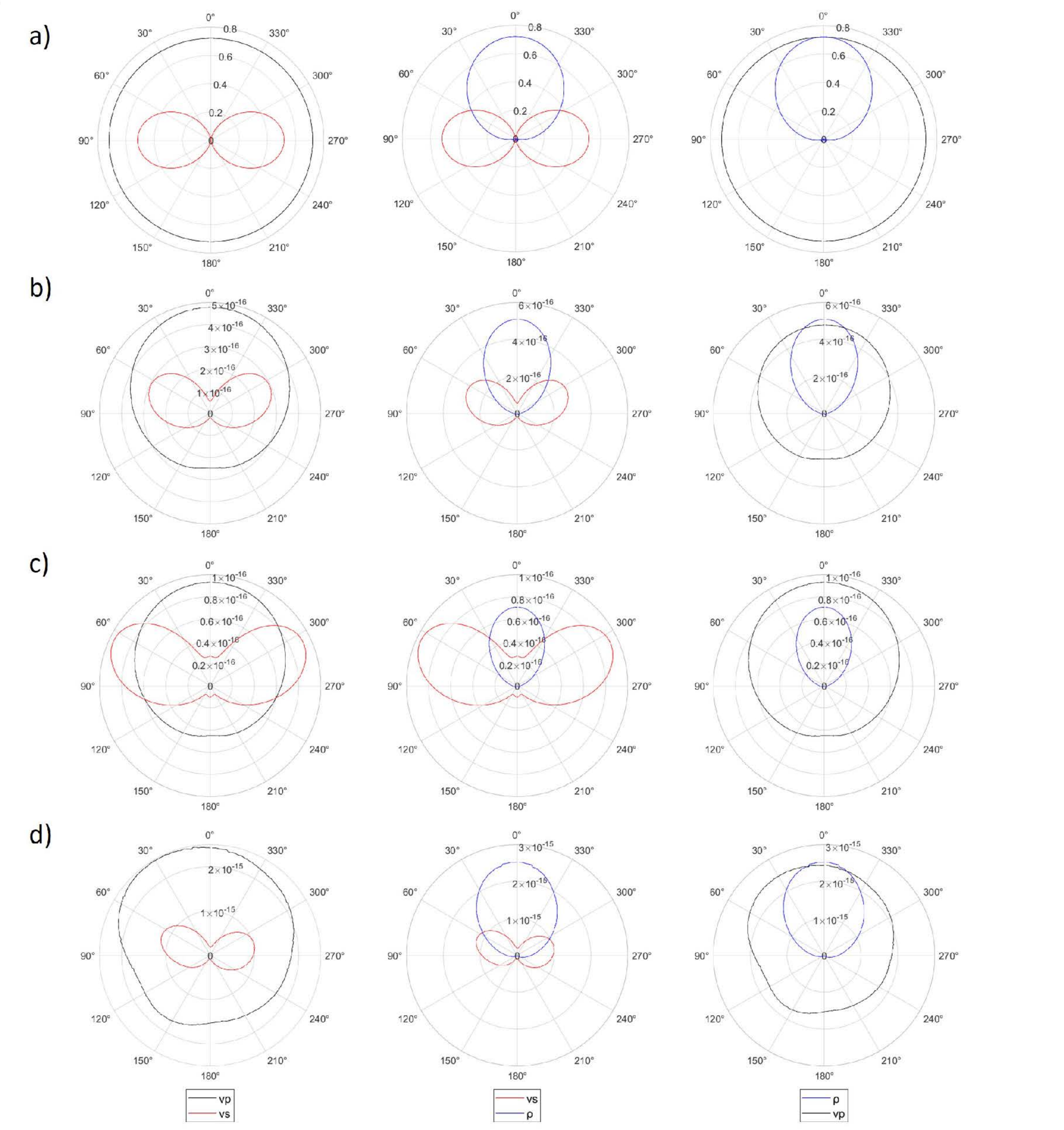

Figure 6. Radiation patterns from P-P wavefield. (a) Analytic expressions, (b) case 1, (c) case 2, and (d) case 3.

Conclusions

The proposed workflow enables to extract empirical radiation patterns with high accuracy, allowing to perform crosstalk analysis in heterogeneous subsurface configurations or using re-parameterizations where the analytic expressions are unknown. Although the shape of the radiation patterns with heterogeneous backgrounds is close to the indicated by the analytic formulas, rotation of lobes, decrease of amplitudes and loss of symmetry or irregularities might occur. Moreover, the overlap of these patterns demonstrated that the crosstalk regions slightly change with respect to those indicated by the analytic expressions and different sensitivities between patterns are also present, having impact on the inversion of the observed data.

References

Sato, H., Fehler, M. C., and Maeda, T., 2012, Seismic Wave Propagation and Scattering in the Heterogeneous Earth: Springer, 2 edn

NSERC CRSNG
UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
Department of Geoscience