Sensitivity Kernels for Receiver Functions - Prelimenary results from the Groningen Gas Field

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Receiver Functions Adjoint Sources

To assess the ability of receiver functions (Vinnik 1977, Langston 1979) to determine the depth of shallow layer boundaries in a regional, and possible time variable setting such as the Groningen gas-field, we have derived the adjoint sources (Tarantola 1984, Tromp et al. 2005) for a receiver function waveform misfit:

$$\chi = \frac{1}{2}\left[RF^{syn}(\mathbf{x}_r, m, t) - RF^{obs}(\mathbf{x}_r, t)\right]^2$$

We found the adjoint sources to be:

$$f_R^{\dagger}(\mathbf{x}, T-t) = F^{-1}\left[\frac{\Delta RF(\mathbf{x}_r, \omega)}{u_V^{*}(\mathbf{x}_r, \omega)}\right]\delta(\mathbf{x}-\mathbf{x}_r)$$

$$f_V^{\dagger}(\mathbf{x}_r, T-t) = F^{-1}\left[\frac{\Delta RF(\mathbf{x}_r, \omega)u_R^{*}(\mathbf{x}_r, \omega)}{u_V^{2*}(\mathbf{x}_r, \omega)}\right]\delta(\mathbf{x}-\mathbf{x}_r)$$

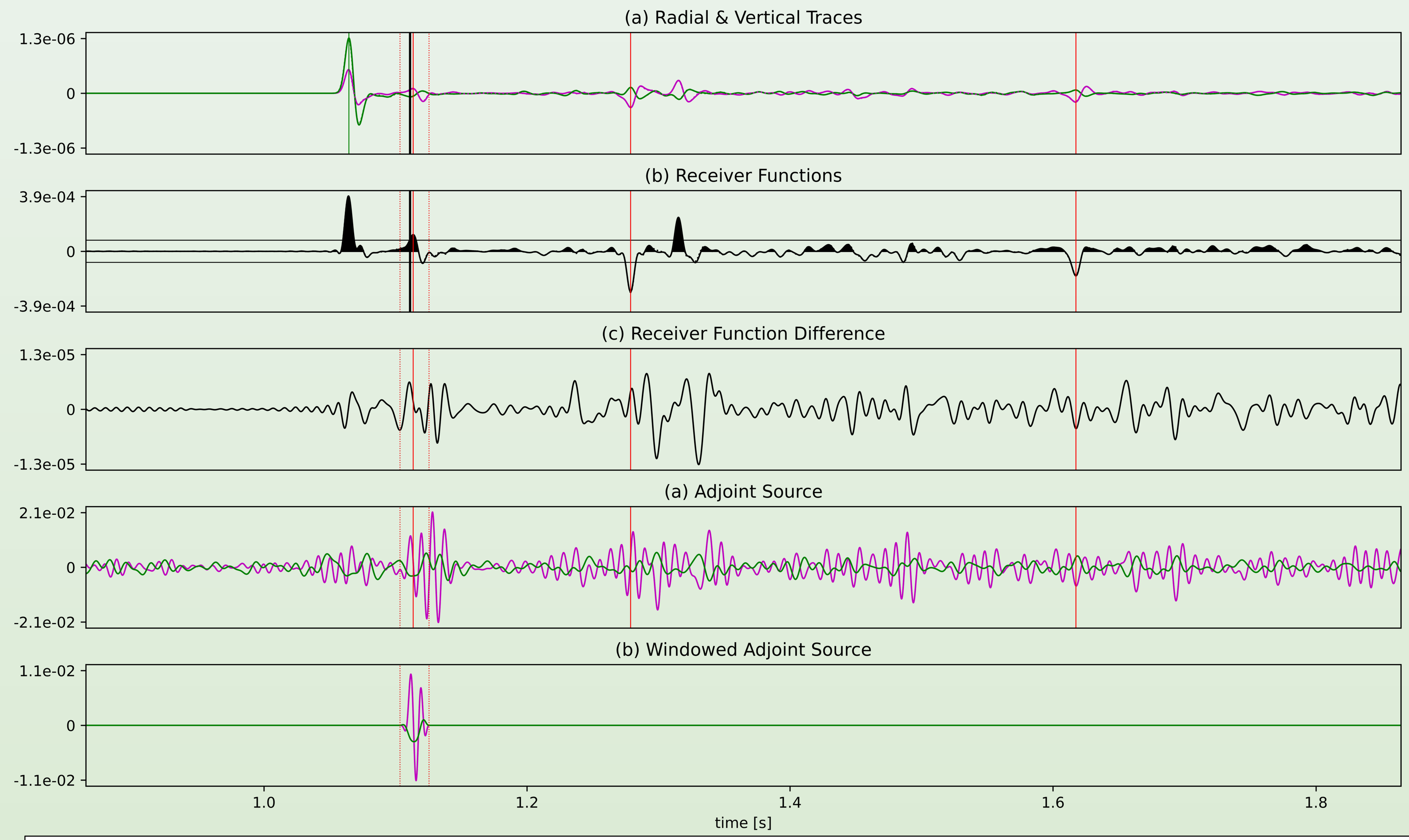

Figure 1: Traces, receiver functions and adjoint sources for the bottom geophone**.** Red lines indicate arrivals.

We calculate the sensitivity kernels using synthetic data (figure 1) from 2D models of the Groningen Gas field (figure 3 & 4). This data is based on real test shots (figure 2) measured at a borehole near Stedum. In figure 1, we show the synthetic traces, the receiver functions, their difference, and the adjoint sources for the lowest reservoir geophone. In figure 2, we show the synthetic and real receiver functions for all 10 geophones in the reservoir.

Sensitivity Kernels

In figure 3 & 4, we show the senstivity kernels and the 2D-model. The most important observations are:

1. Significant P-wave speed sensitivity (α-kernel) before conversion
2. Strong sensitivity to S-wave speed after conversion.
3. Sensitivity to reflections or conversions in the impedance kernel (ρ').

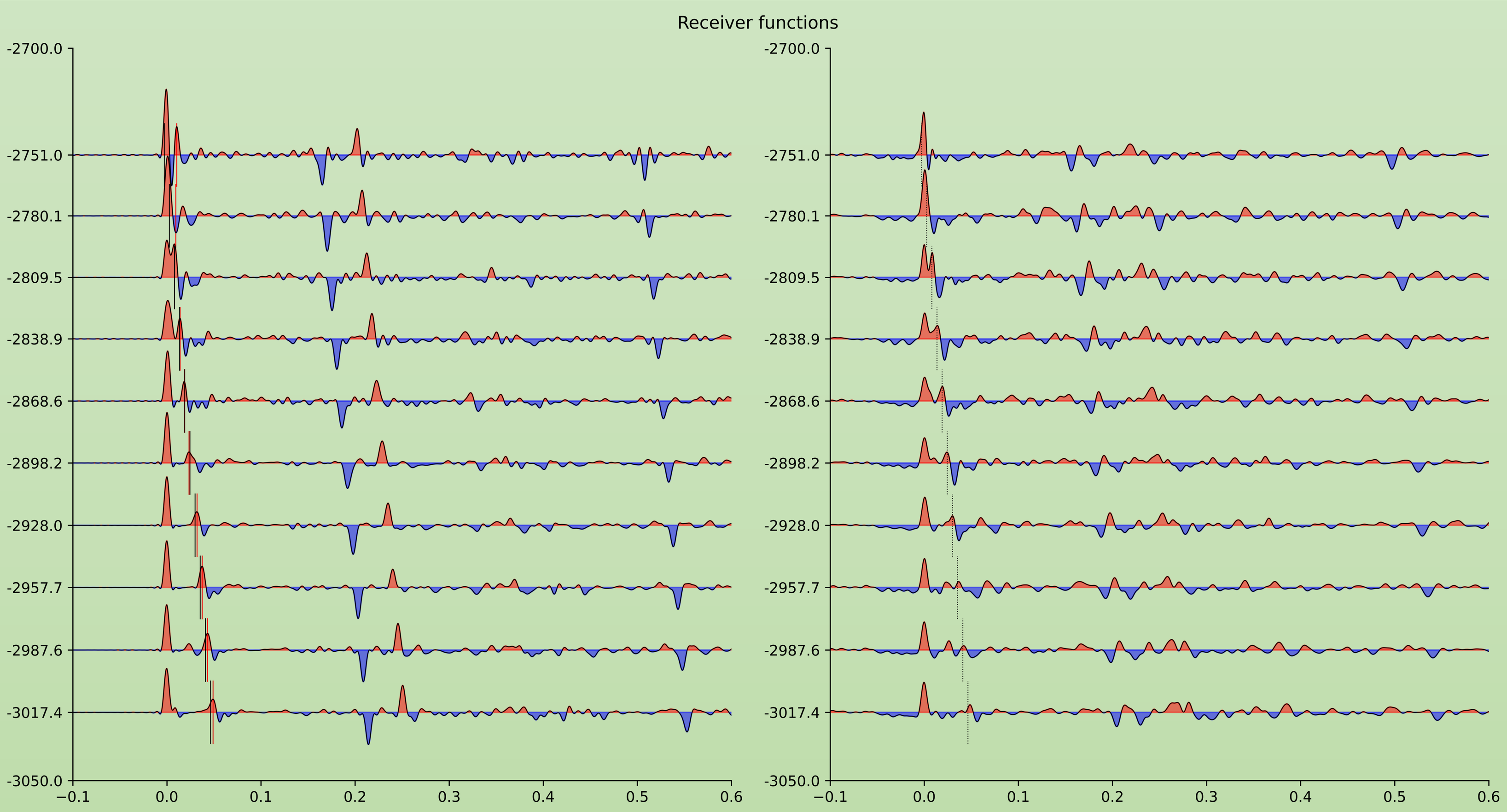

Figure 2: Synthetic (left) and real (right) receiver functions for 10 borehole geophones.

Objective: Application in Groningen Context

Here we show our first, very preliminary, results. In the continuation of this work, we hope to investigate what information borehole receiver functions contain. Borehole receiver functions allow us to partly bypass both the unconsolidated upper layers, with all their challenges, as well as the source mechanism. Our results indicate that sensitivity kernels can help identify where conversions observed in receiver functions originate. We hope to see whether these kernels might be used to detect temporal variations within the reservoir or within the overburden. Using receiver functions, we can focus in particular on the depth of layer boundaries.

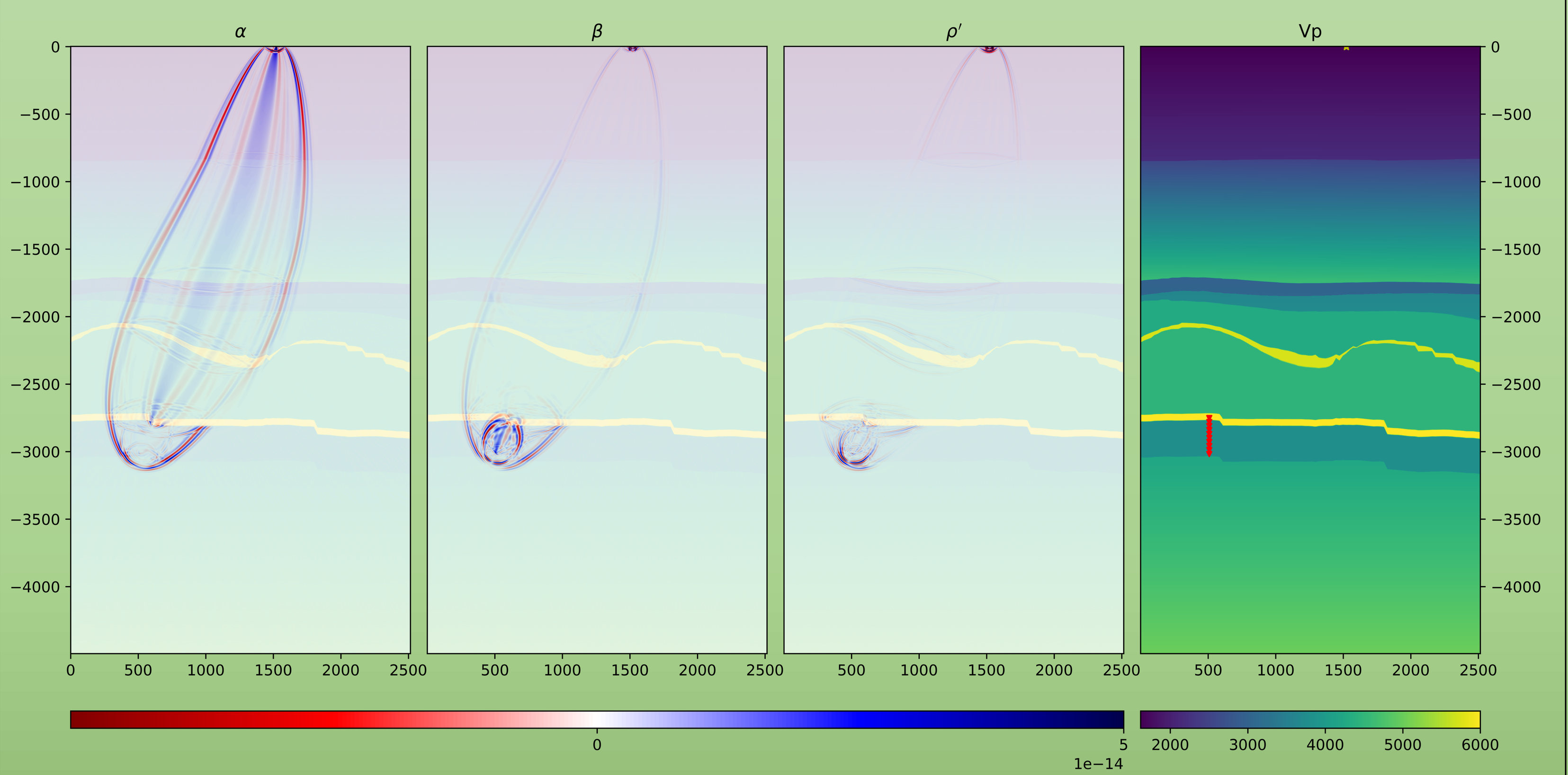

Figure 3: Kernels for Vp (α), Vs (β), and impedance (ρ'). At the right: the Vp-model with the geophones (red) and source (yellow), for the first arrival (see fig. 1).

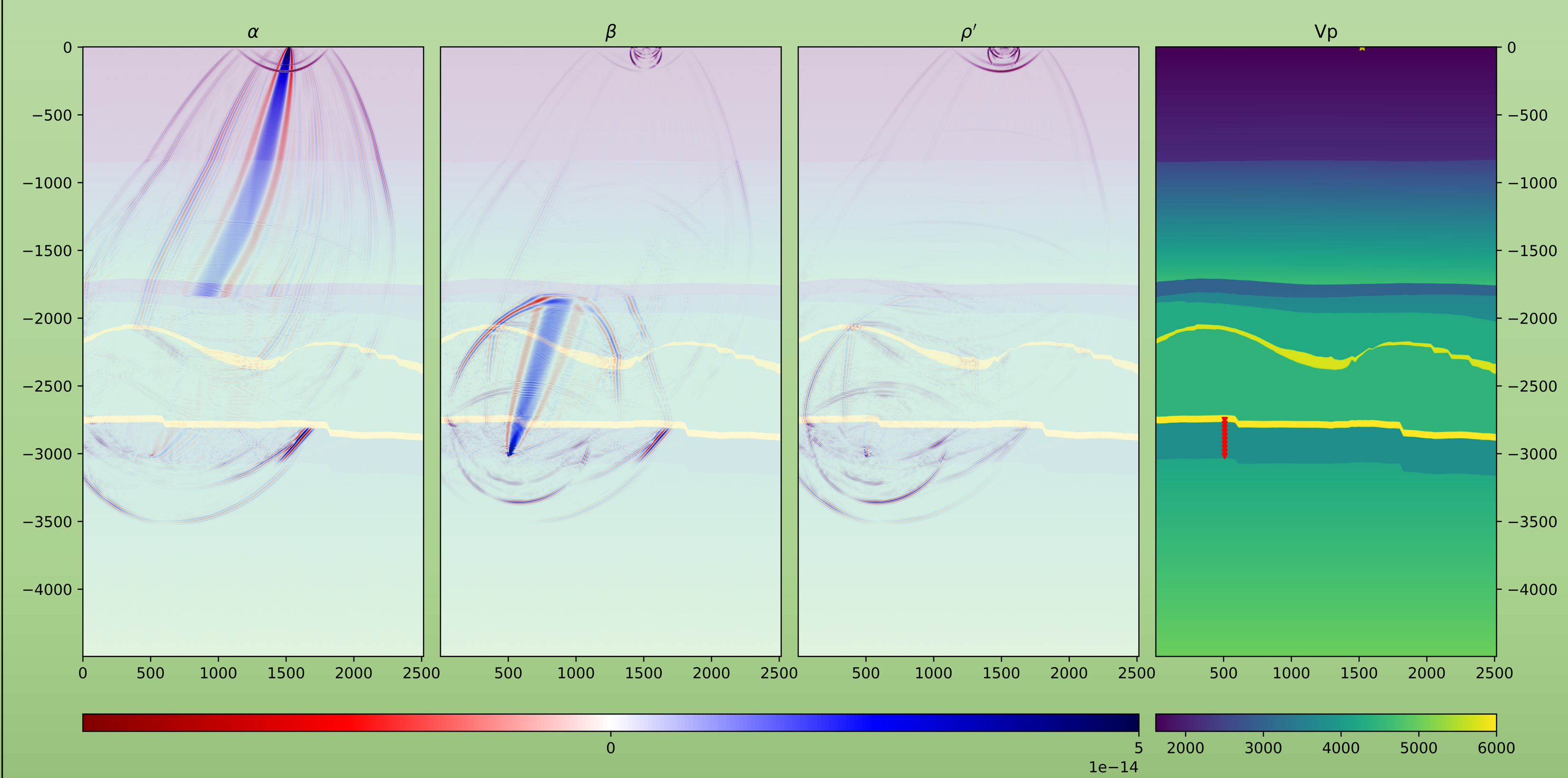

Figure 4: Sensitivity kernels and model, same as figure 3, but for the second arrival (2nd red, vertical line shown in figure 1).

References:

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