Up-down wavefield retrieval in boreholes using single-component data

Yi Liu

- Introduction
- Method
- Examples
- Conclusions

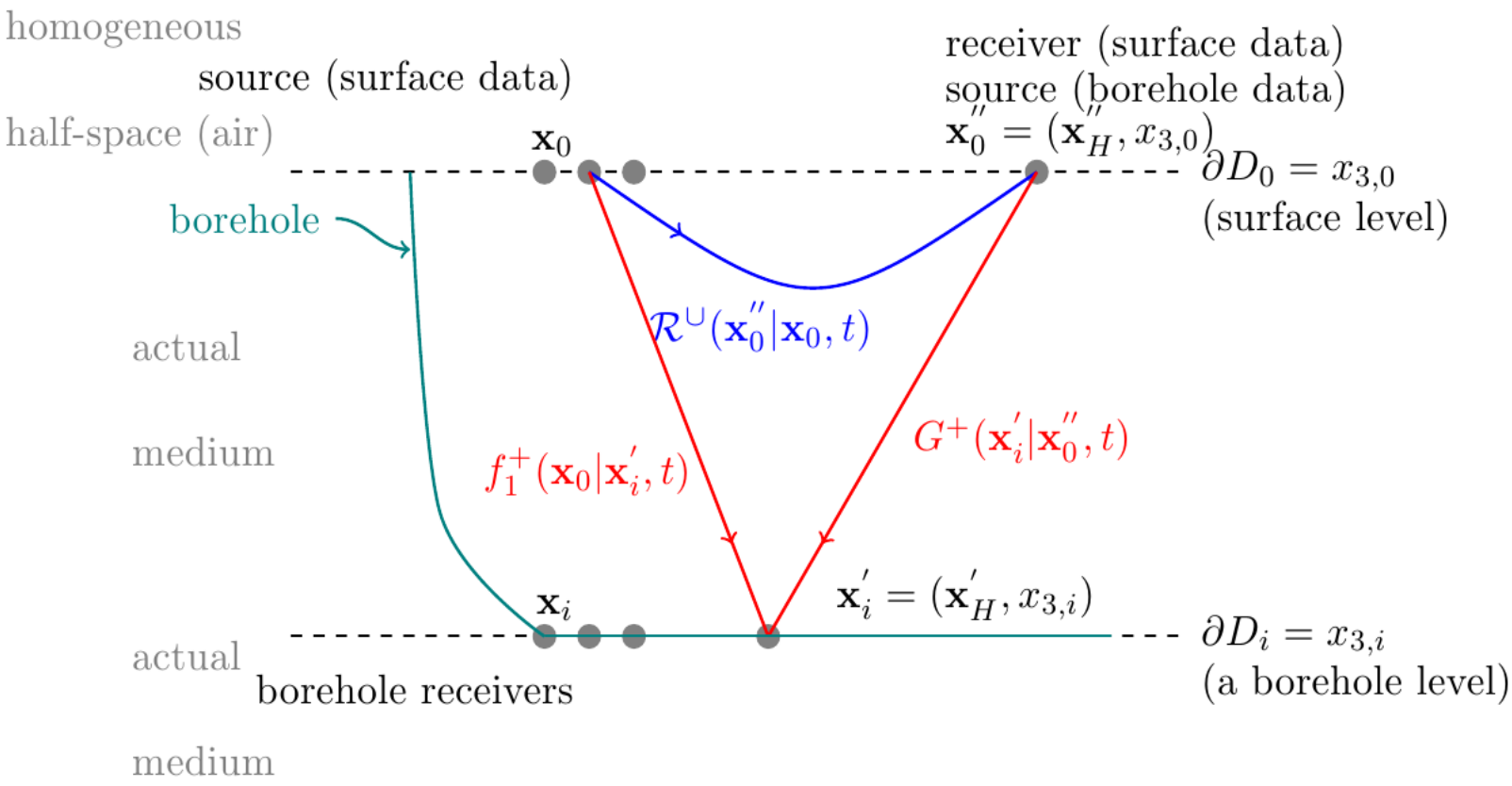
Introduction

- Different apparent velocity: f-k filter (Embree et al., 1963, Treitel et al., 1967), median filter (Stewart, 1985), tau-p domain separation (Moon et al., 1986), ...

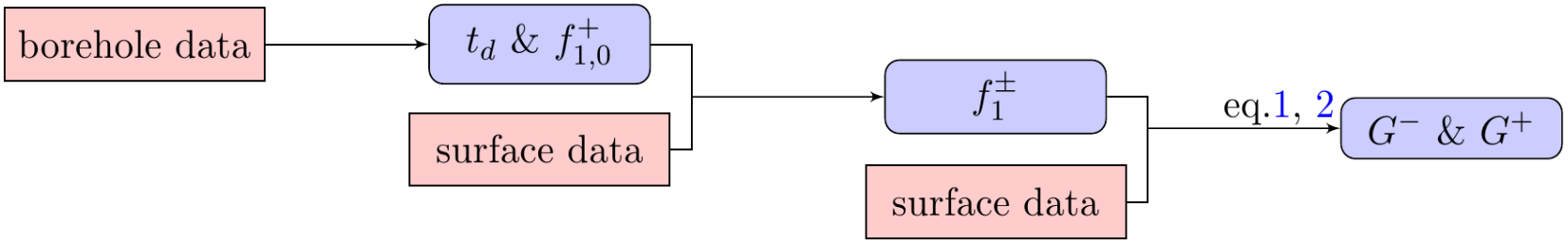
- Wave-equation based using multi-component data: PZ summation (Barr and Sanders, 1989), angle-dependent decomposition (Amundsen and Reitan, 1995)

- Wave-equation based using single-component data: retrieve from surface reflection data

Introduction



Method



$$t \geq t_d(\mathbf{x}_0^{''}|\mathbf{x}_i^{'})$$

$$G^-(\mathbf{x}_i^{'}|\mathbf{x}_0^{''},t) = \int_{\partial D_0}\int_{-\infty}^{t} \mathcal{R}^{\cup}(\mathbf{x}_0^{''}|\mathbf{x}_0, t-t^{'}) f_1^+(\mathbf{x}_0|\mathbf{x}_i^{'},t^{'}) dt^{'} d\mathbf{x}_0 \quad (1)$$

$$G^+(\mathbf{x}_i^{'}|\mathbf{x}_0^{''},t) = f_{1,0}^+(\mathbf{x}_0^{''}|\mathbf{x}_i^{'},-t) - \int_{\partial D_0}\int_{-\infty}^{t} \mathcal{R}^{\cup}(\mathbf{x}_0^{''}|\mathbf{x}_0, t-t^{'}) f_1^-(\mathbf{x}_0|\mathbf{x}_i^{'},-t^{'}) dt^{'} d\mathbf{x}_0. \quad (2)$$

(Wapenaar et al., 2014)

To find f_1^+ :

$$f_{1,k}^{+}(\mathbf{x}_0^{''}|\mathbf{x}_i^{'},t) = f_{1,0}^{+}(\mathbf{x}_0^{''}|\mathbf{x}_i^{'},t)+\theta(t+t_d(\mathbf{x}_0^{''}|\mathbf{x}_i^{'}))\int_{\partial D_0}\int_{-\infty}^{\infty}\mathcal{R}^{\cup}(\mathbf{x}_0^{''}|\mathbf{x}_0^{'},t^{'})f_{1,k-1}^{-}(\mathbf{x}_0^{'}|\mathbf{x}_i^{'},t+t^{'})dt^{'}d\mathbf{x}_0^{'}, \tag{3}$$

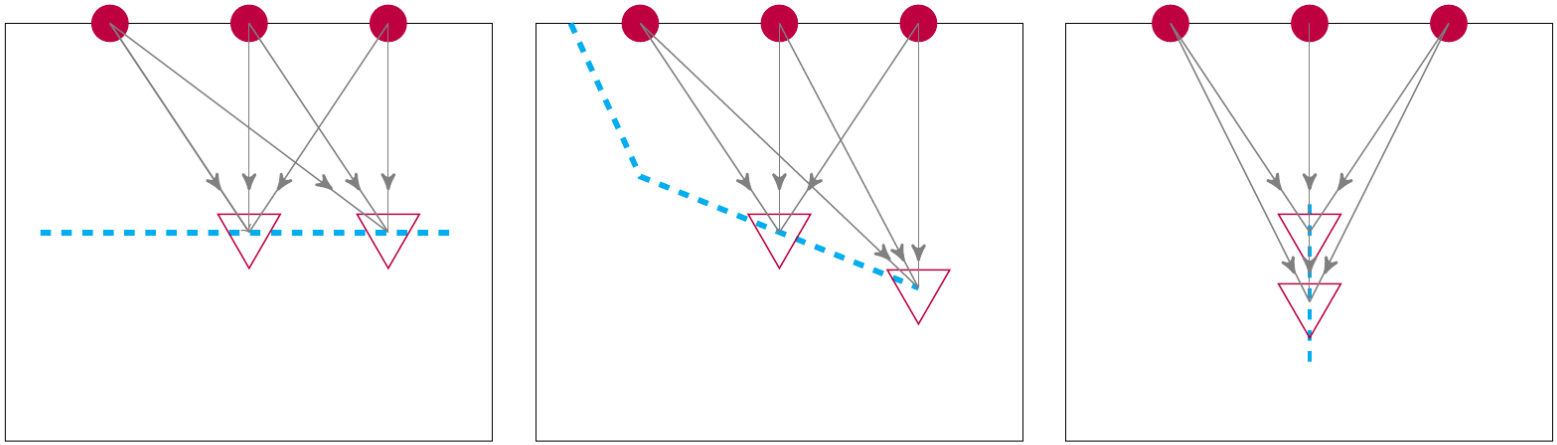
$$f_{1,k}^{-}(\mathbf{x}_0^{''}|\mathbf{x}_i^{'},t) = \theta(t_d(\mathbf{x}_0^{''}|\mathbf{x}_i^{'})-t)\int_{\partial D_0}\int_{-\infty}^{\infty}\mathcal{R}^{\cup}(\mathbf{x}_0^{''}|\mathbf{x}_0^{'},t-t^{'})f_{1,k}^{+}(\mathbf{x}_0^{'}|\mathbf{x}_i^{'},t^{'})dt^{'}d\mathbf{x}_0^{'}, \tag{4}$$

with

$$f_{1,0}^{+}(\mathbf{x}_0^{''}|\mathbf{x}_i^{'},t) \approx G_d(\mathbf{x}_i^{'}|\mathbf{x}_0^{''},-t), \tag{5}$$

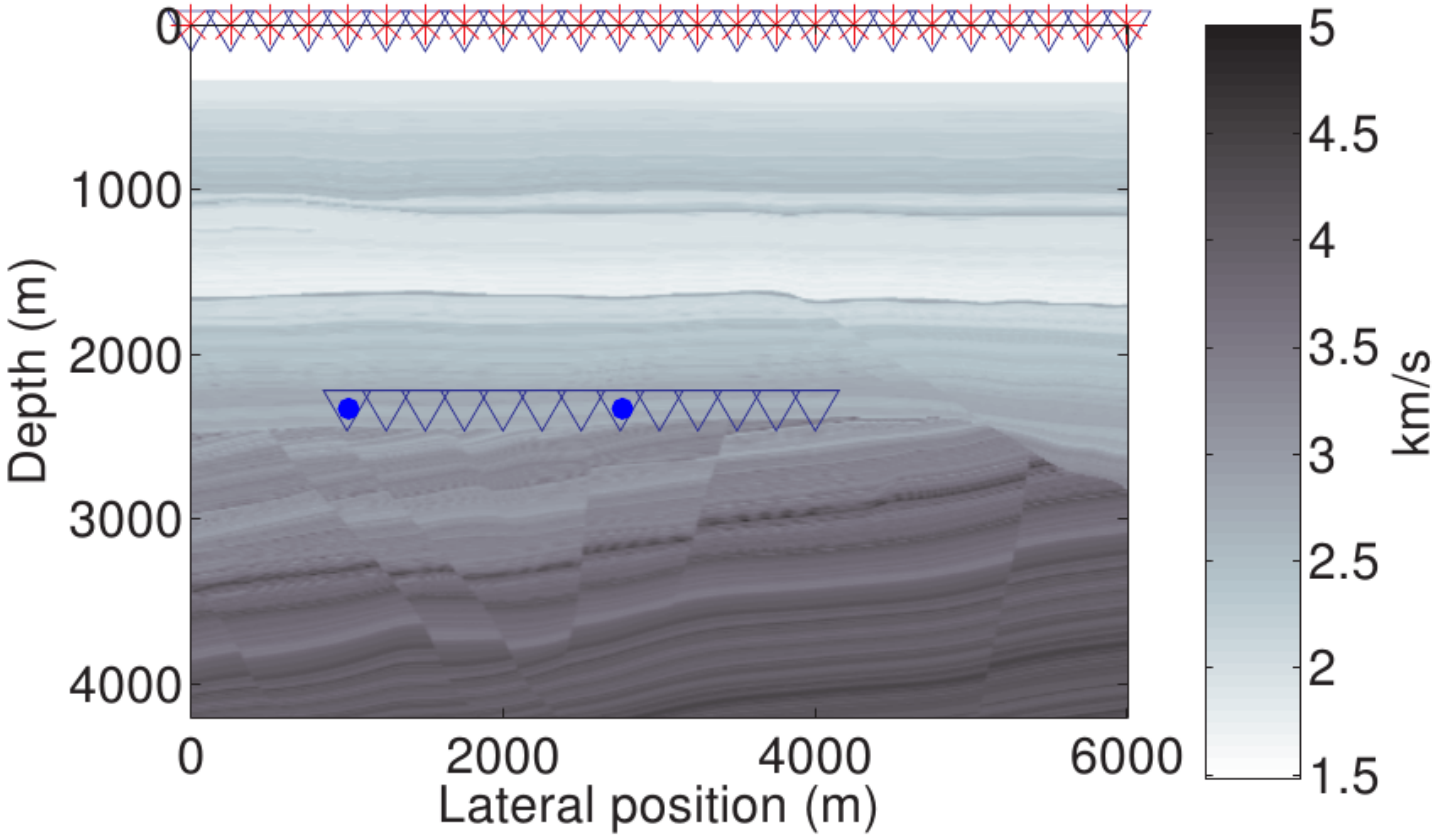
(Rose, 2002; Broggini et al., 2012, ...)

Method



a) b) c)

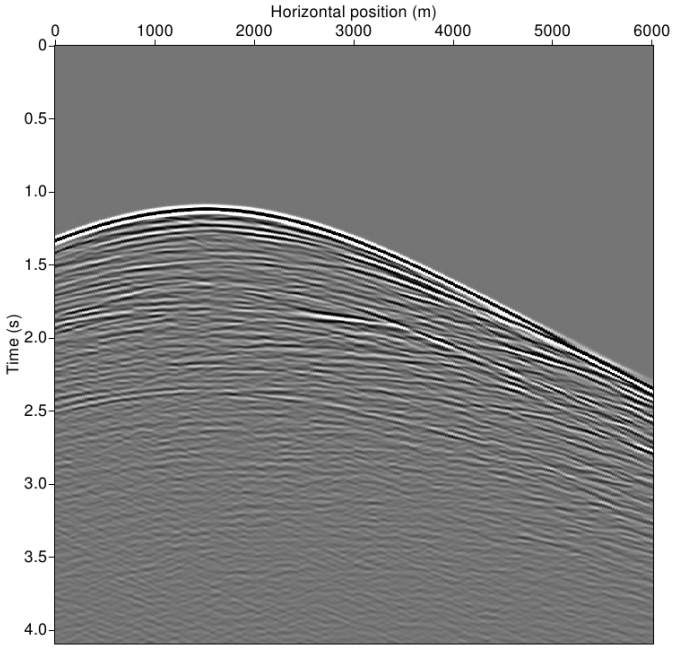
Example 1: horizontal case



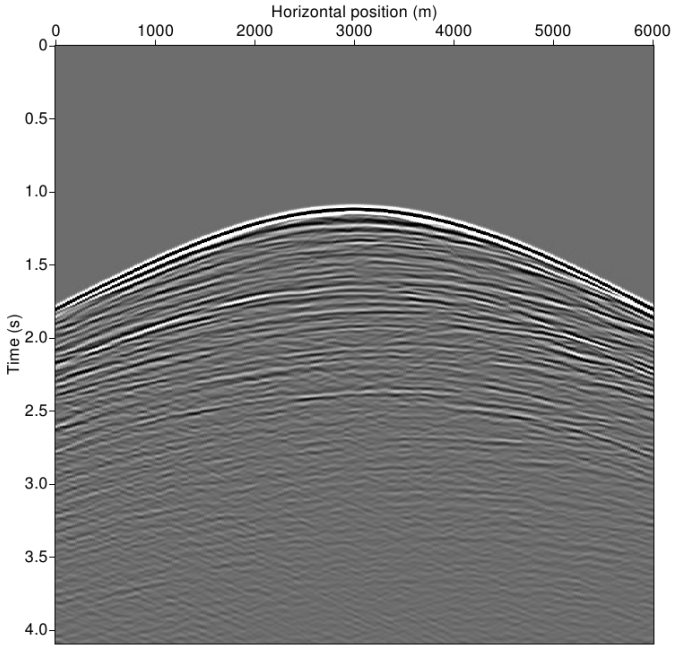
Surface: nsrc = nrcv = 241; dsrc = drcv = 25 m; fmax = 55 Hz.

Borehole: nrcv = 129; drcv = 25 m; zrcv = 2300 m; Ricker, 15 Hz.

Example 1: common-receiver gather, borehole data

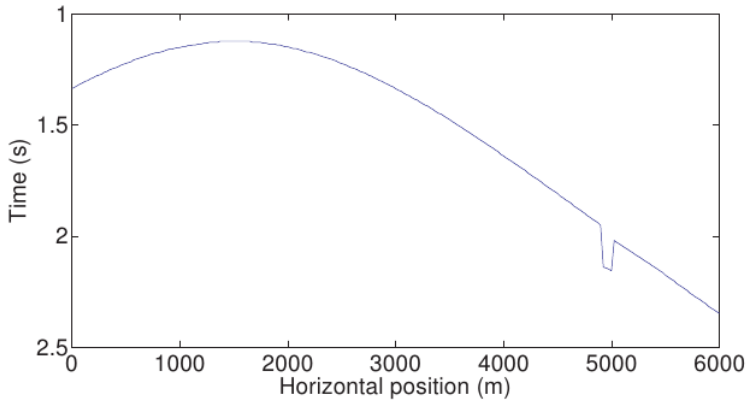


a)

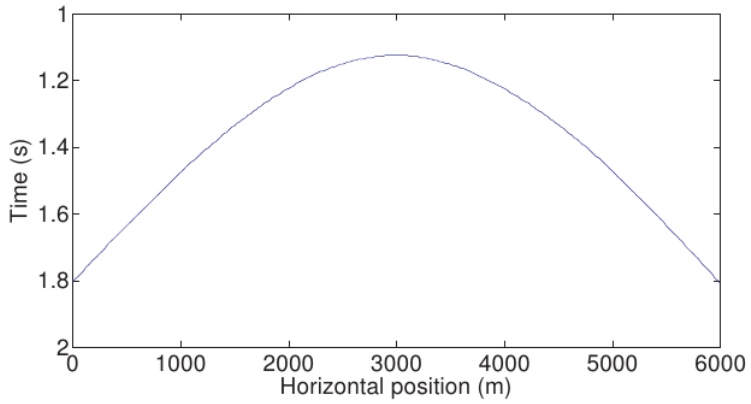


b)

Example 1: direct arrivals' traveltime curves



a)



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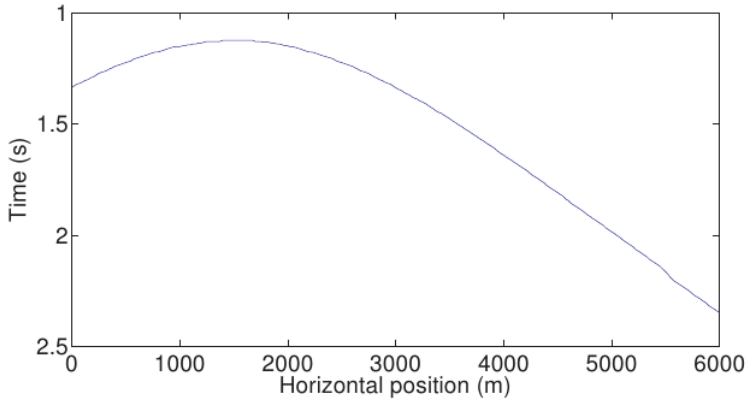
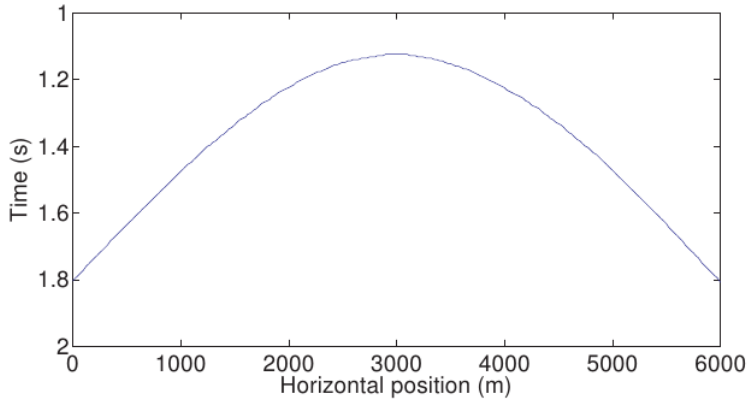
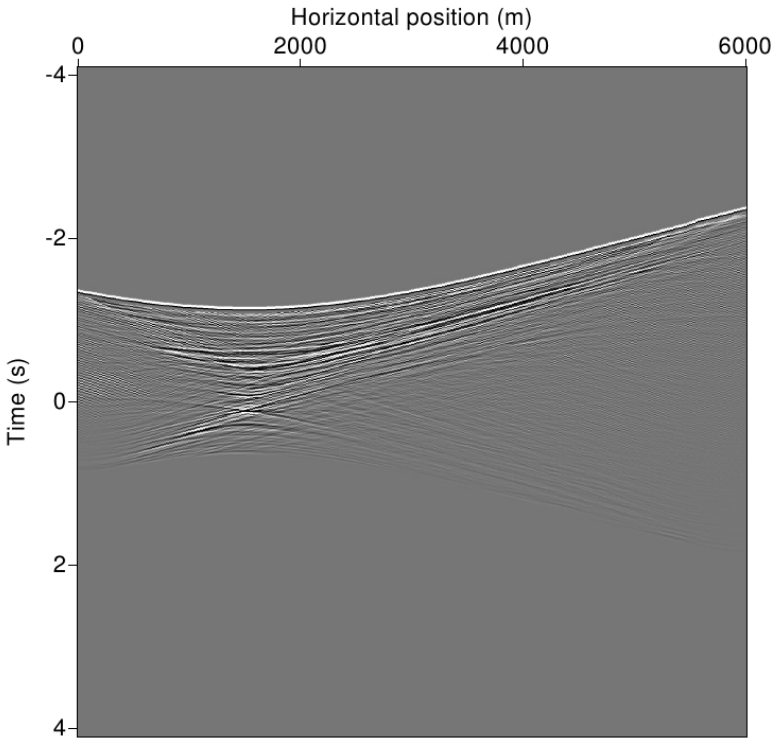


c)

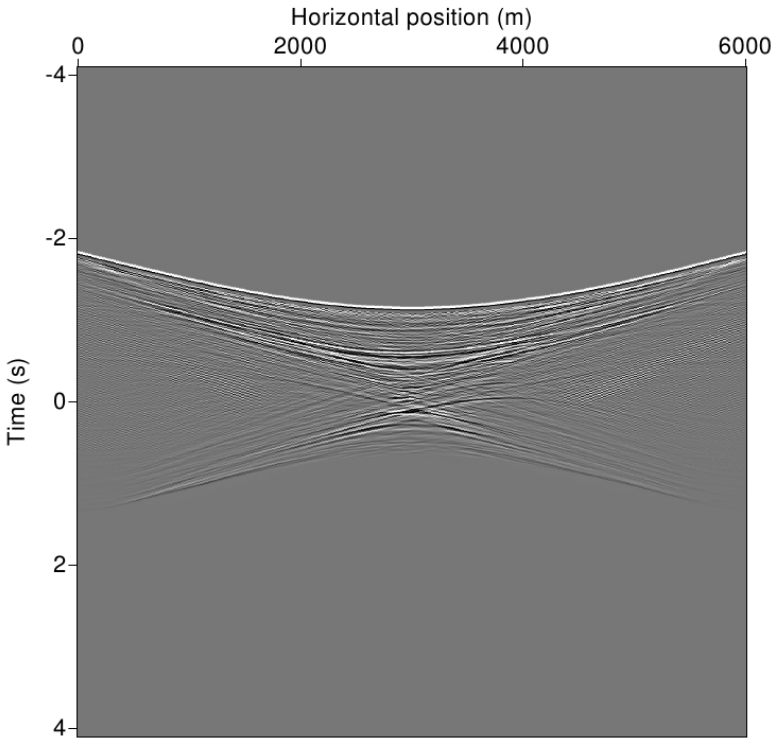


d)

Example 1: computed focusing functions f_1^+

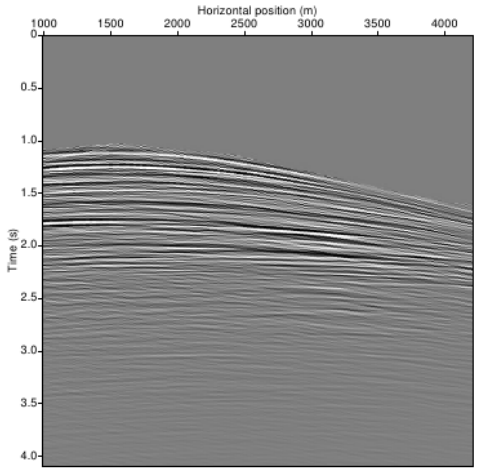


a)

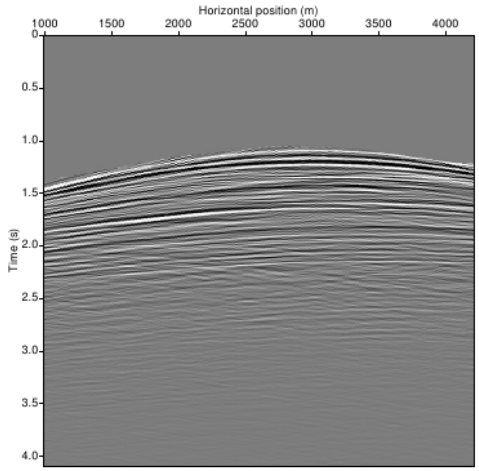


b)

Example 1: comparison of the upgoing wavefields

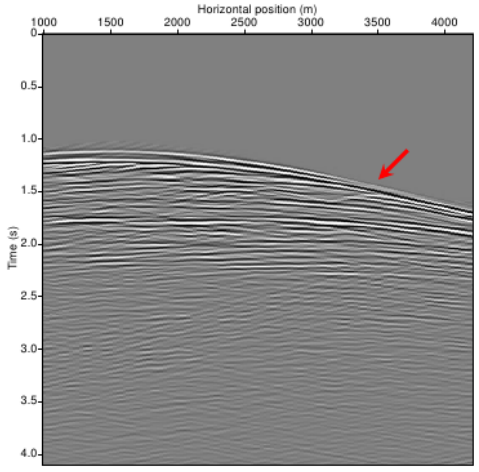


a)



b)

single-component



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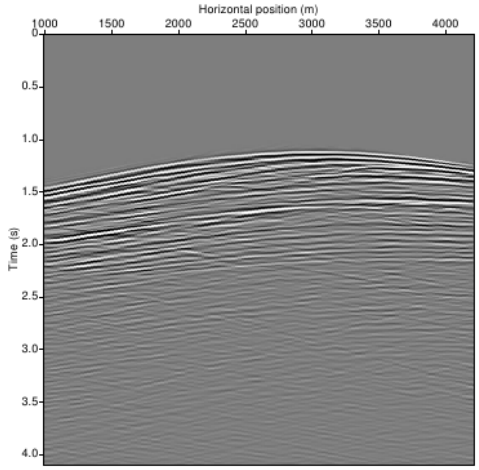
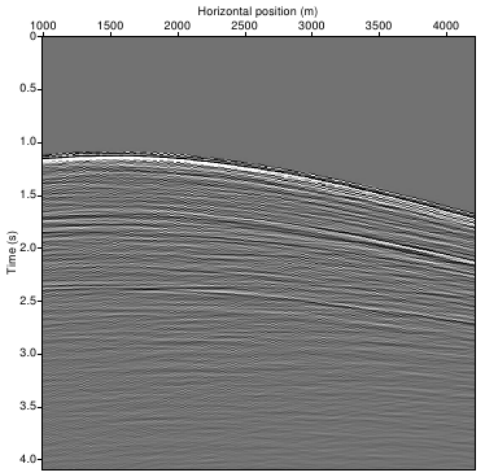


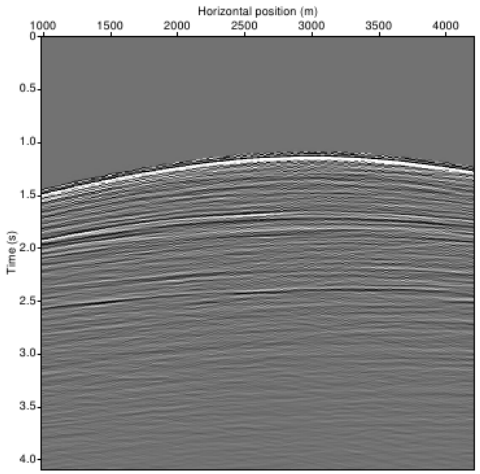
d)

multi-component

Example 1: comparison of the downgoing wavefields

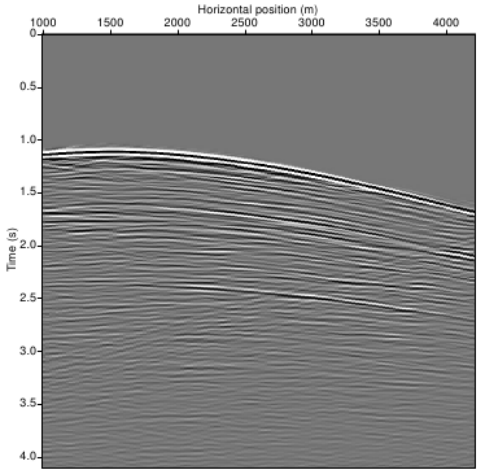


a)

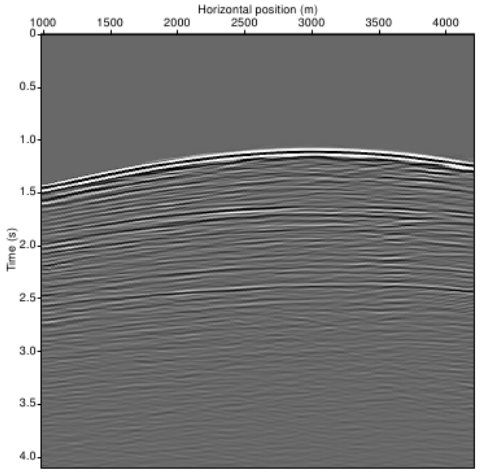


b)

single-component



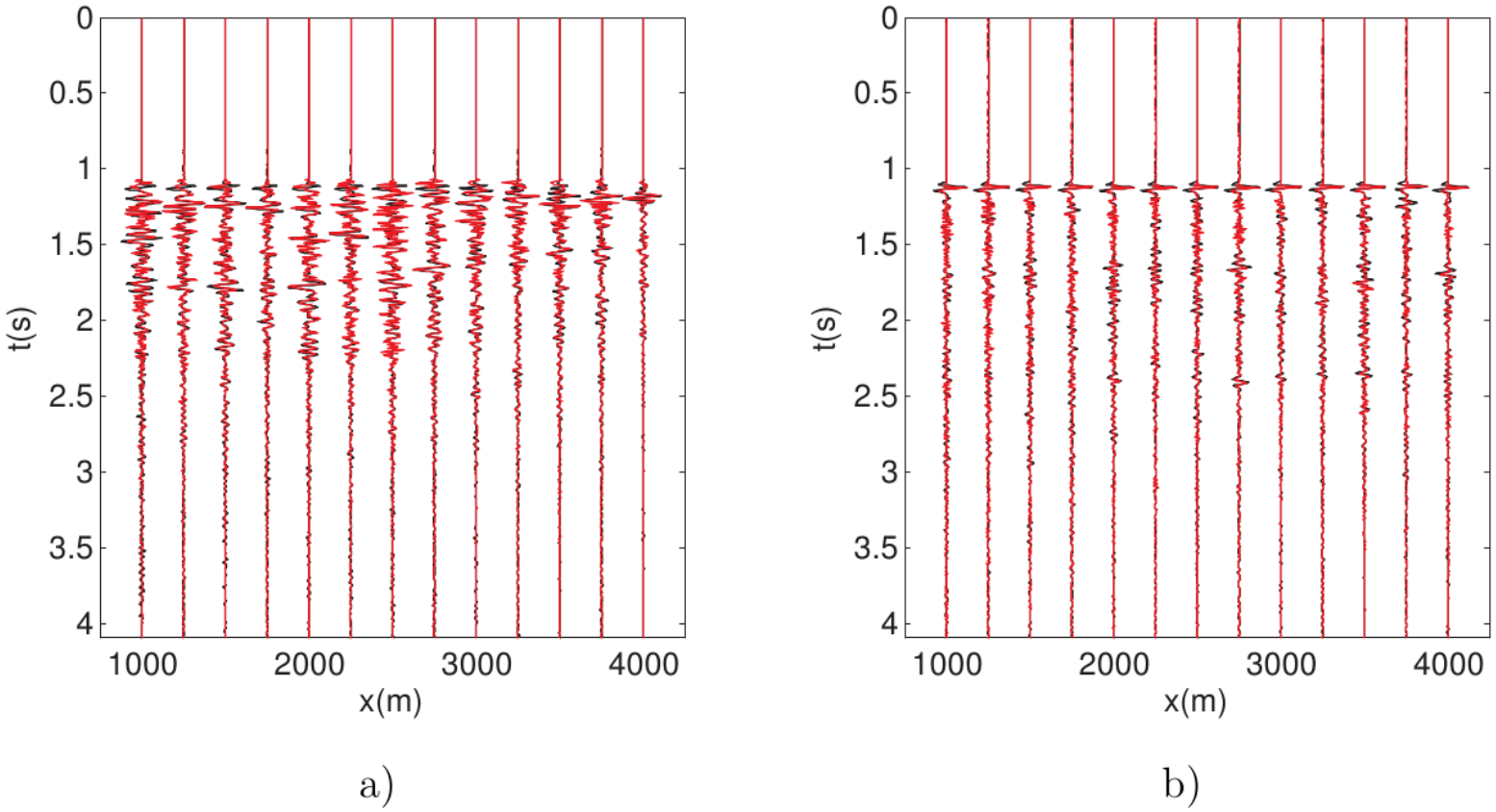
c)



d)

multi-component

Example 1: comparison of the zero-offset



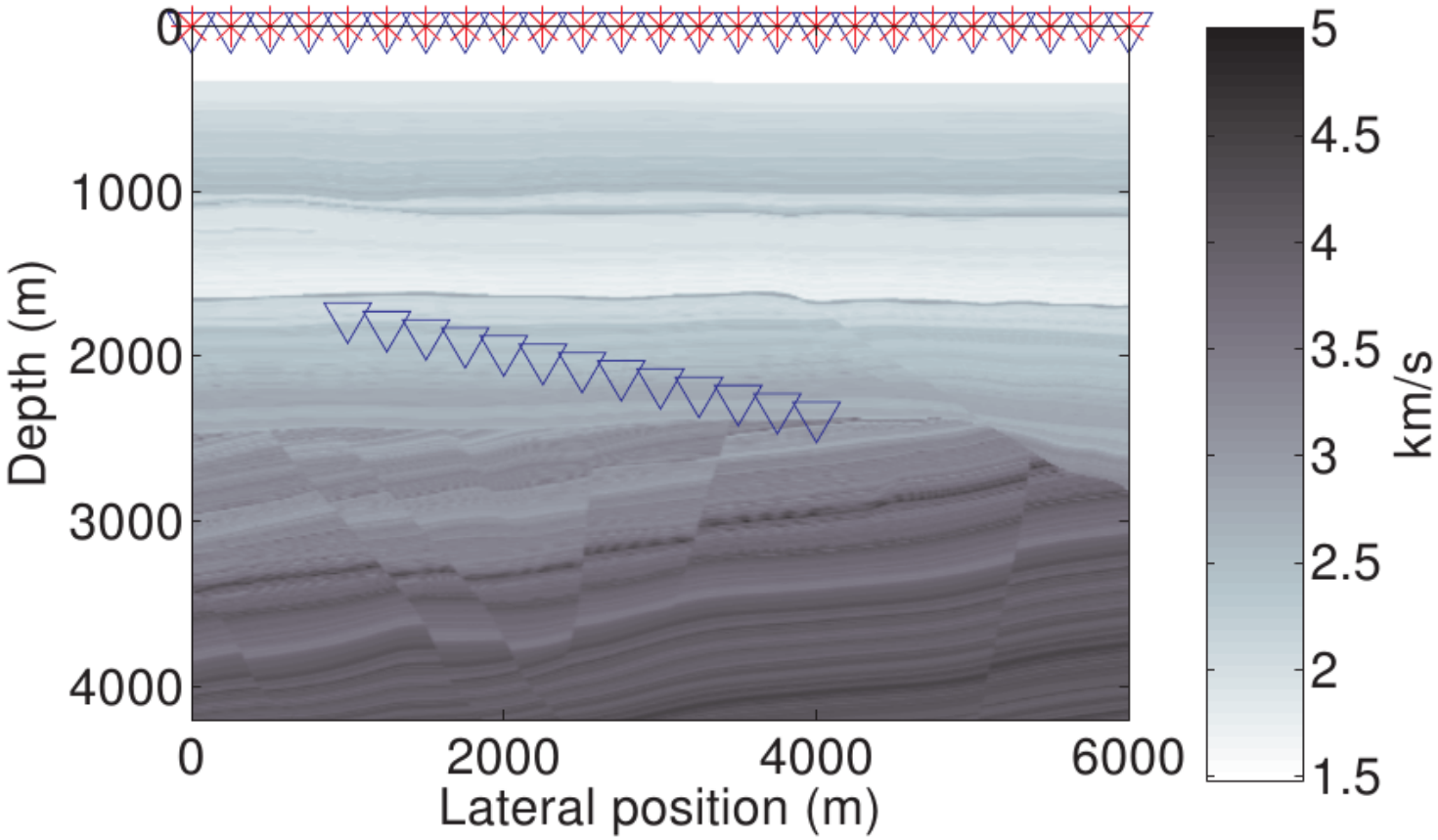
a) The upgoing wavefield

b) The downgoing wavefield

red: the single-component approach

black: standard multi-component approach (p and vz).

Example 2: deviated borehole



Surface: nsrc = nrcv = 241; dsrc = drcv = 25 m; fmax = 55 Hz.

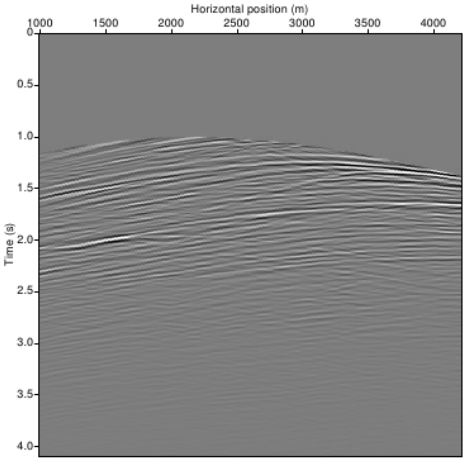
Borehole: nrcv = 129; dxrcv = 25 m; dzrcv = 5 m; zrcv = [1760, 2400] m; Ricker, 15 Hz.

Example 2: comparison of the up-down wavefields

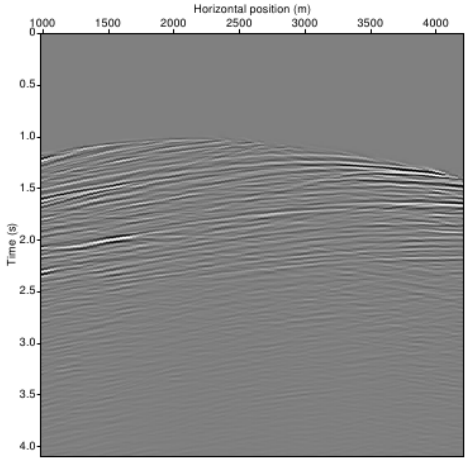
single-component

multi-component

Upgoing

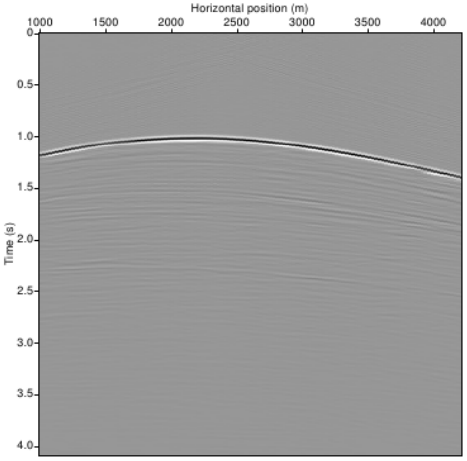


a)

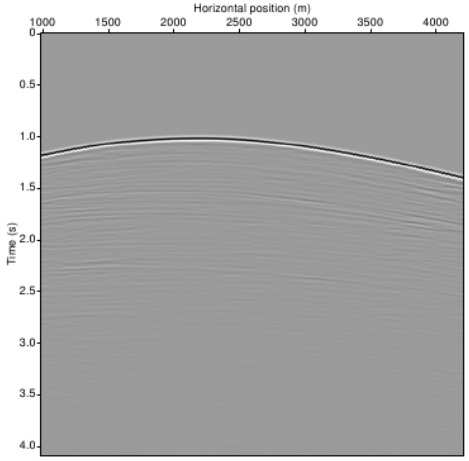


b)

Downgoing

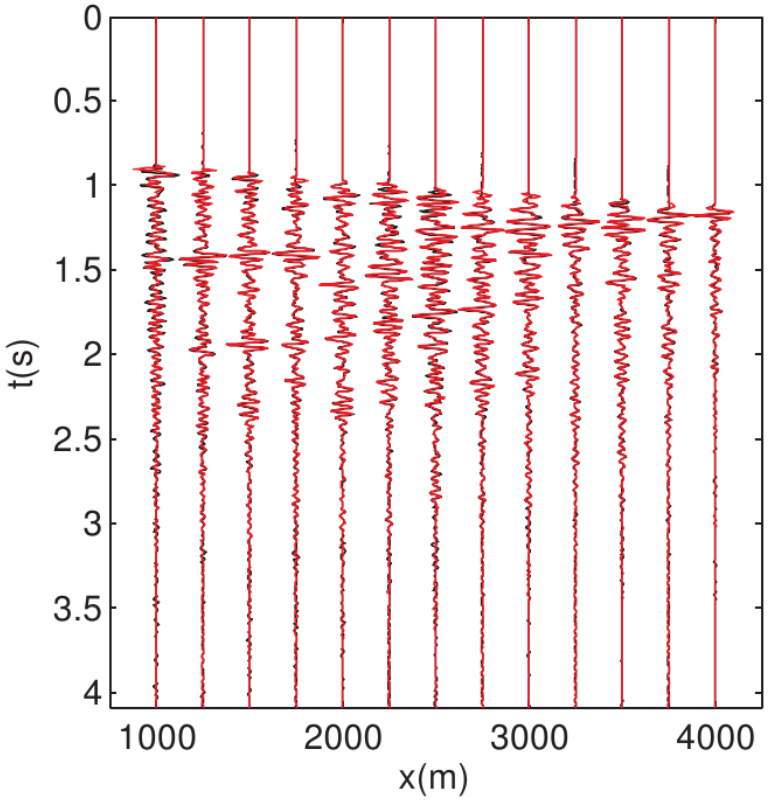


c)

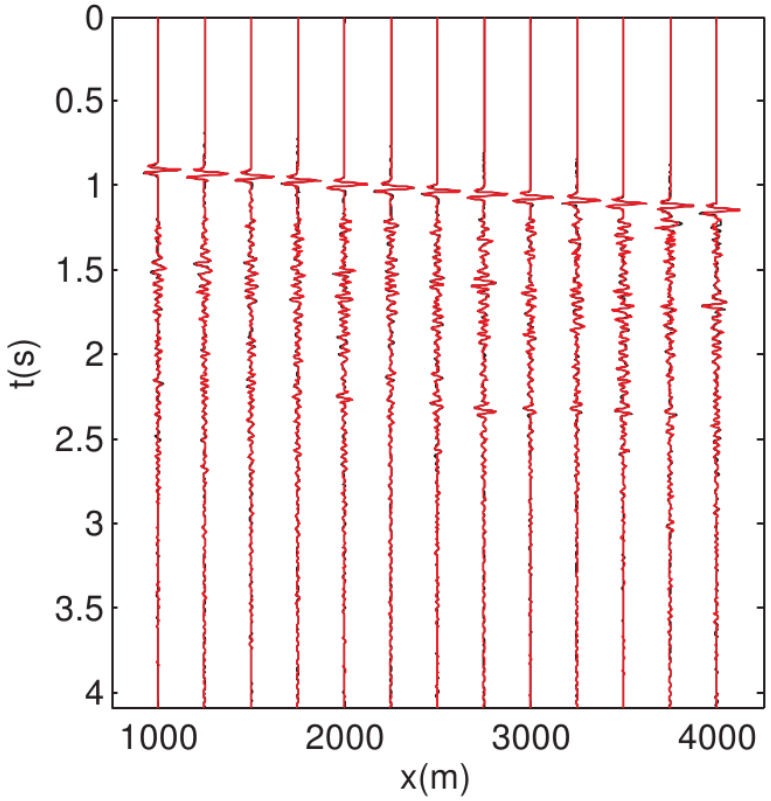


d)

Example 2: comparison of the zero-offset result



a)



b)

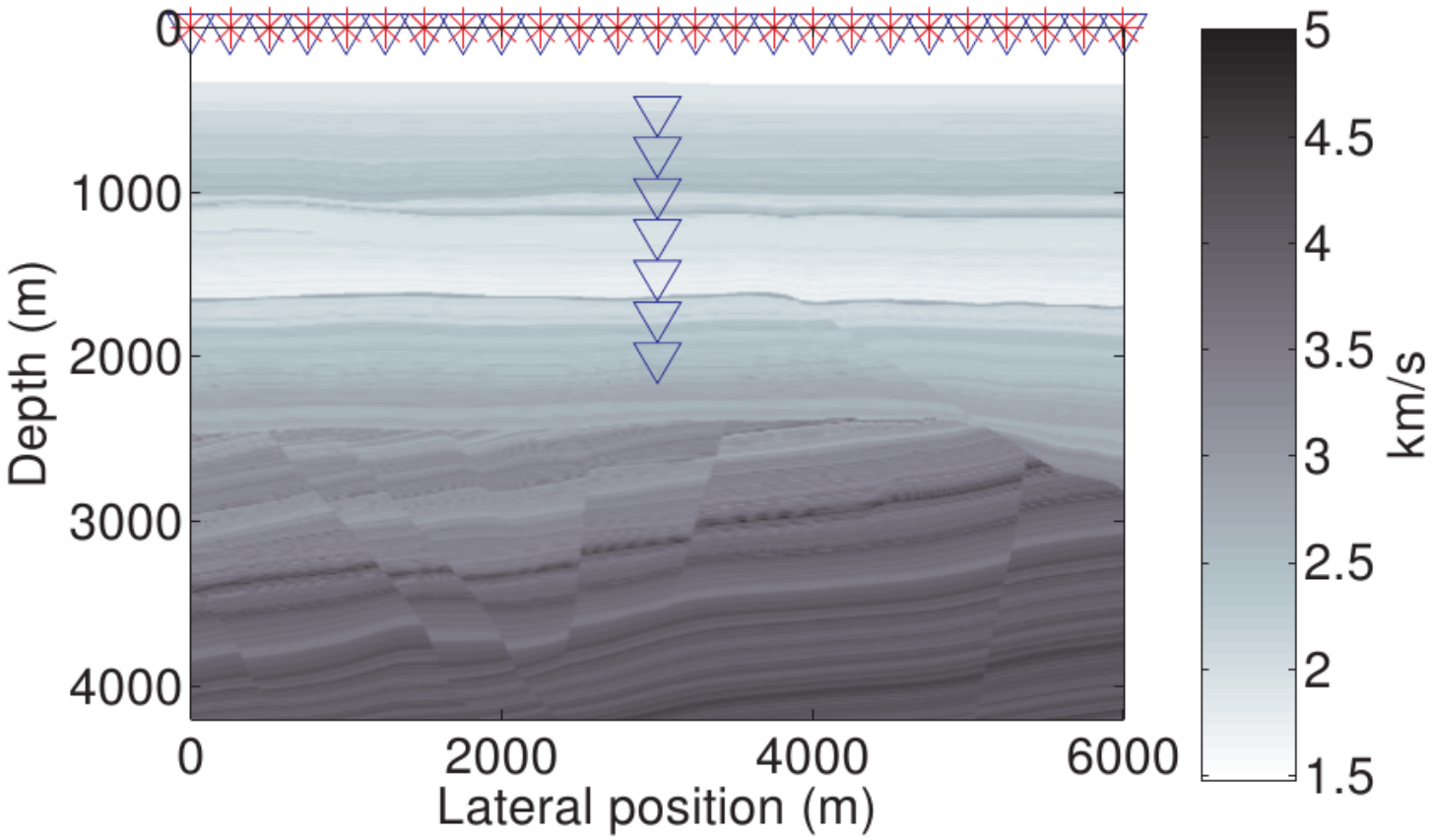
a) The upgoing wavefield

b) The downgoing wavefield

red: the single-component approach

black: standard multi-component approach (p and vz).

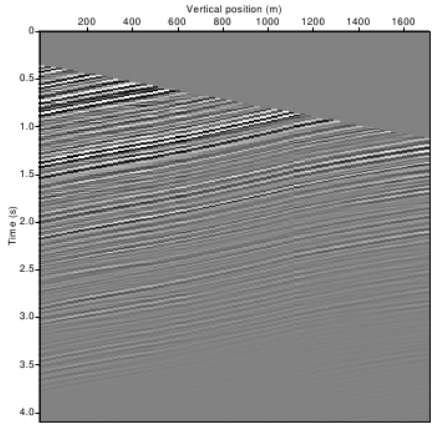
Example 3: vertical borehole



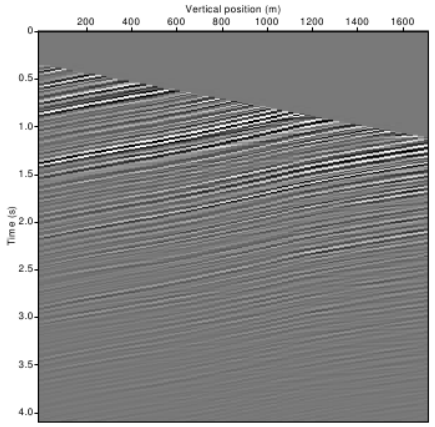
Surface: nsrc = nrcv = 241; dsrc = drcv = 25 m; fmax = 55 Hz.

Borehole: nrcv = 69; dzrcv = 25 m; zrcv = [500, 1200] m; Ricker, 15 Hz.

Example 3: comparison of the up-down wavefields



a)



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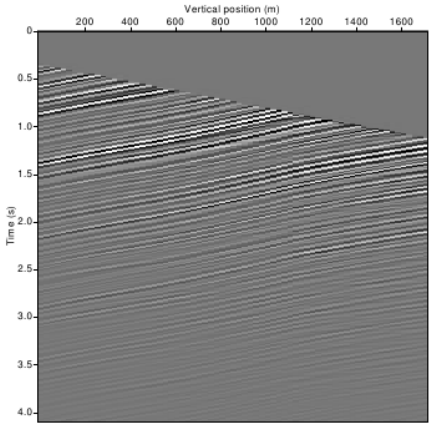

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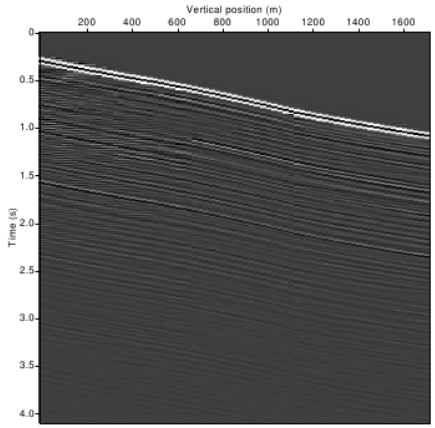

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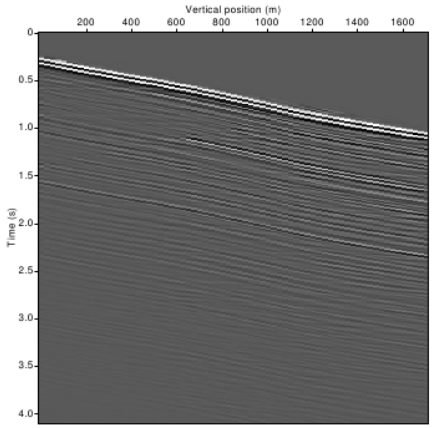
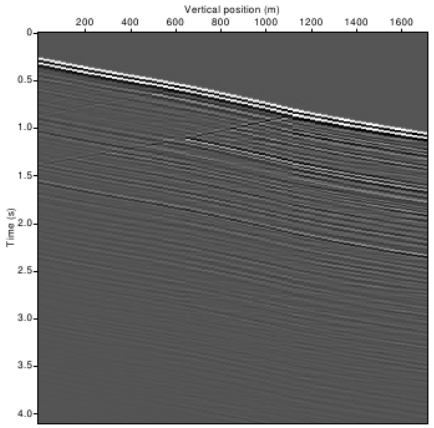


e)



f)

Single-component

single-component (with f-k dip filtering)

multi-component (PZ summation)

Discussion

Advantages:

- General lossless inhomogeneous medium, but smooth variation near the borehole;
- Wave-equation based, so all internal multiples are taken into account;
- No medium property information needed. No velocity error effect;
- Not limited to horizontal boreholes;
- Can be applied to a single borehole receiver, no receiver array need.

Practical consideration:

- A good surface reflection response required: source wavelet deconvolution, surface multiple removal (SRME), a wide source and receiver coverage at the surface;
- Regularization of the source locations from the surface and borehole data;
- Limited illumination angle to steep reflectors compared to the actual decomposed borehole data.

Conclusions

- A new single-component approach to retrieve the up-down wavefields in boreholes.
- Good agreement with those obtained by conventional decomposition methods.
- Although multi-component data are commonly available now, the possibility of retrieving the up-down wavefield using existing single-component data without any extra field cost is nevertheless attractive.

Acknowledgements

- ROSE consortium at NTNU
- Jan Thorbecke at TUD for the open source modelling package
- Alexander Kritski at Statoil for the velocity model

References

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Thank you!