Active and passive interferometry with a deepwater OBS array *

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Abstract

This work discusses active and passive interferometry with ocean bottom seismometers (OBS) for the purpose of shallow subsurface imaging. Compared to conventional seismic processing, active interferometry suppresses the need of survey source position knowledge and removes statics. However, the shooting times frames optimally the crosscorrelations and was found to reduce interferences from other acoustic sources. Horizontal resolution is limited to half the receiver spacing.

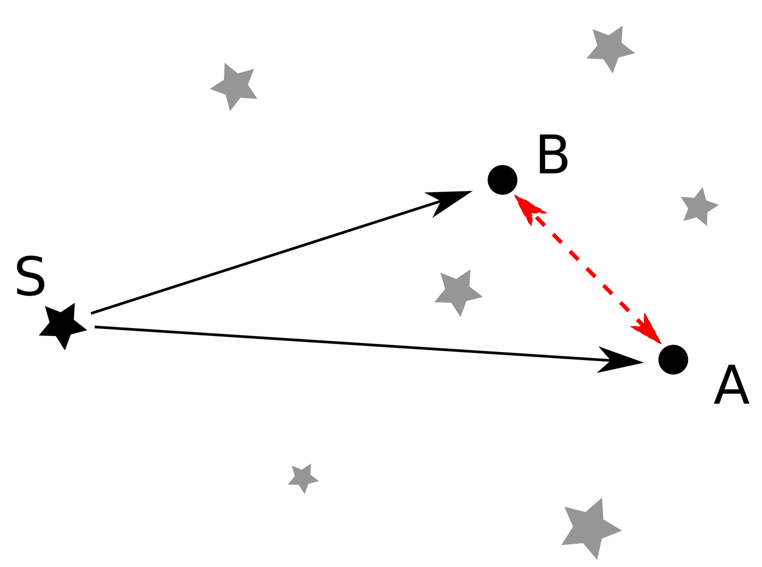
Ambient noise interferometry removes the need of active surveys but typically requires long term recording for the reflection peak to emerge. In the frequency regime considered here (10–100 Hz), waveguide (horizontal) propagation might dominate the spectrum and array processing is required to remove interferers (spatial filtering or PCA), using dense arrays. Horizontal noise might be further attenuated by considering 2D arrays.

Simulation and deepwater data from the Gulf of Mexico illustrate the concepts.

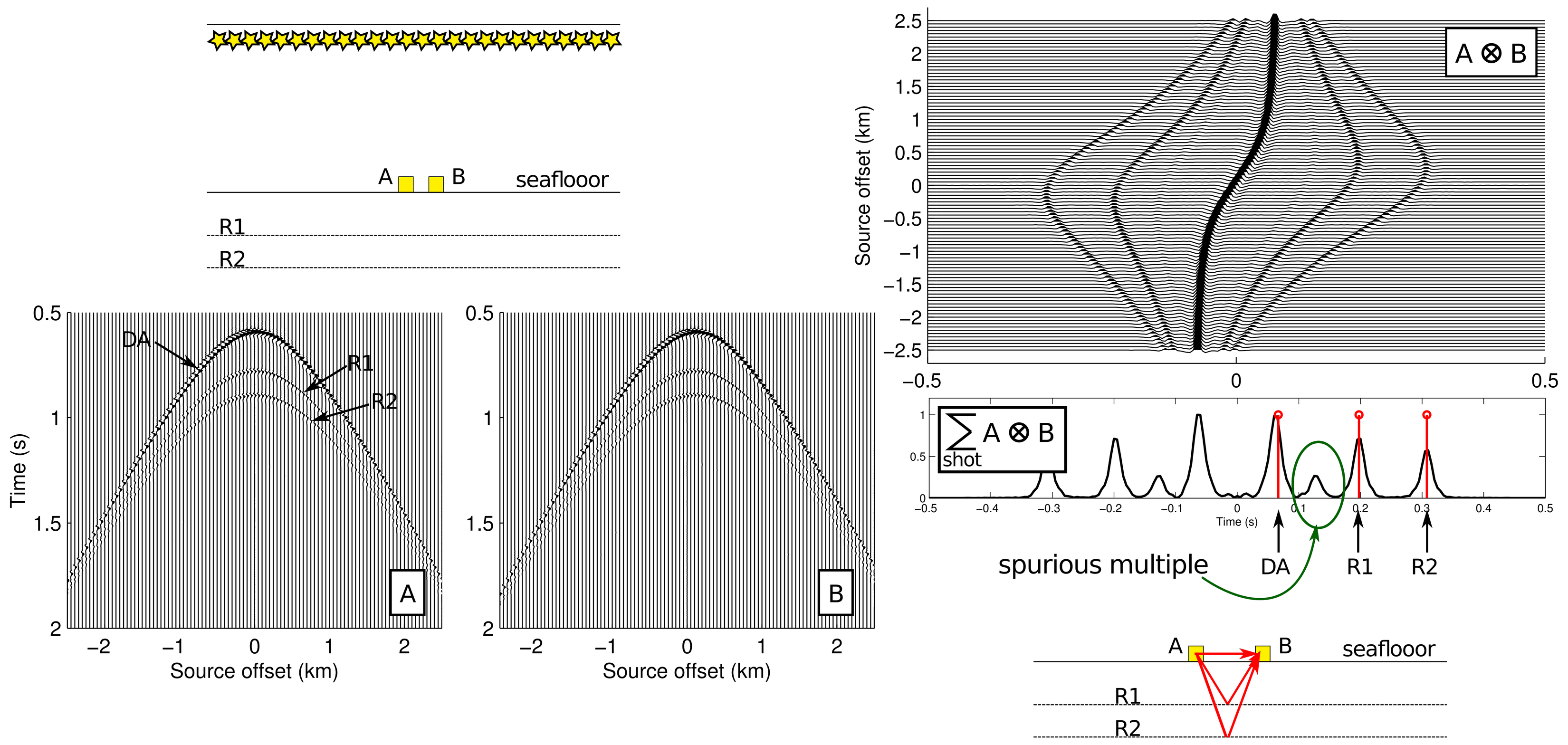
Green's function extraction

- Green's function between two given points can be extracted by crosscorrelating waves recorded at these two points and excited by sources distributed on a closed surface.

$$C_{AB}(\omega) \propto \int_S |S(\omega)|^2 G(\mathbf{r}_A, \mathbf{r}_S) G(\mathbf{r}_B, \mathbf{r}_S) dS \sim G(\mathbf{r}_A, \mathbf{r}_B) - G^*(\mathbf{r}_A, \mathbf{r}_B)$$



- In most situations, receivers are not fully surrounded by sources and the latter are located on a single side of the receiver pair.
- This leads to artifacts in the reconstructed Green's function (spurious multiple).

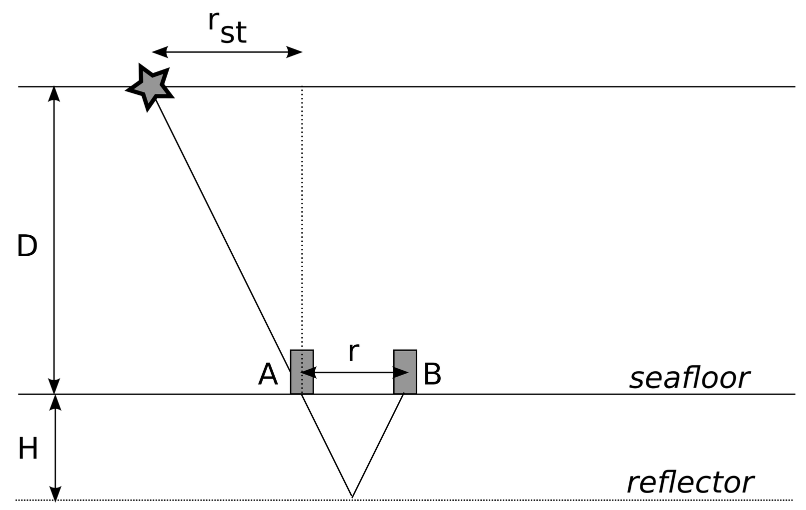


- The finite source offset limits the minimum reflector depths resolved

Given a receiver spacing of r, water depth D and reflector at depth H below the seafloor, the offset r_{st} of the stationary-phase point is

$$r_{\mathrm{st}} = \frac{rD}{2H}.$$

For instance, considering a water depth of $D = 1000$ m and sensors separated by $r = 500$ m, a maximal source offset of 2.5 km cannot resolve reflectors located at less than $H = 100$ m below the seafloor.



Array processing

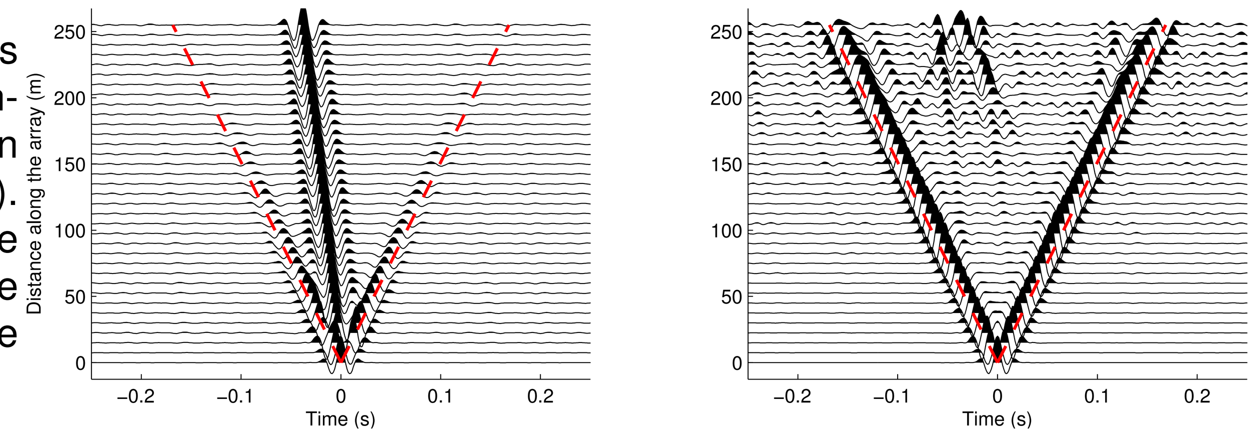
- The covariance matrix $\boldsymbol{R}_{ab} = \mathcal{F}(C_{ab})$ is decomposed in its eigenvectors and eigenvalues

$$\boldsymbol{R} = [\boldsymbol{e}_1 \ldots \boldsymbol{e}_N]\Lambda[\boldsymbol{e}_1 \ldots \boldsymbol{e}_N]^H \quad \text{where } \Lambda = \mathrm{diag}\{\lambda_j\}$$

- Principal component analysis (PCA) enables the separation between directional and ambient noise

$$\boldsymbol{R} = \sum_{i=1}^{K} \lambda_i \boldsymbol{e}_i \boldsymbol{e}_i^H + \sum_{j=K+1}^{N} \lambda_j \boldsymbol{e}_j \boldsymbol{e}_j^H$$

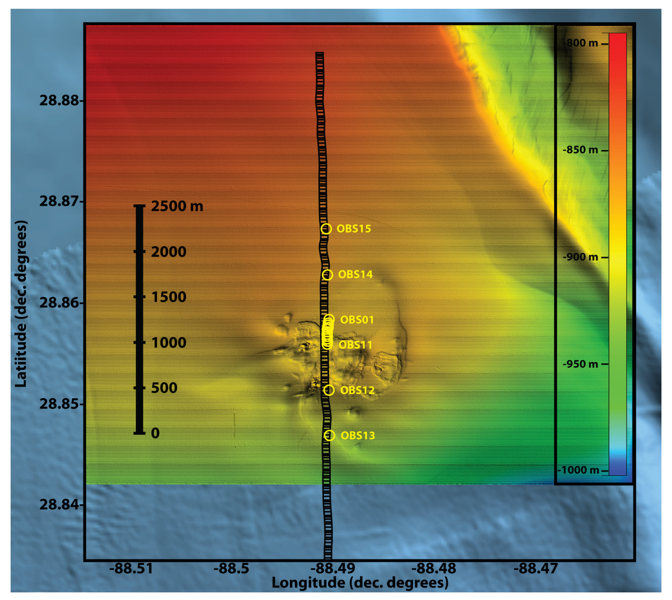
An interferer biases the surface noise generated time-domain Green's function (a). After re-weighting the largest eigenvalue, the direct arrivals (red) are enhanced (b).

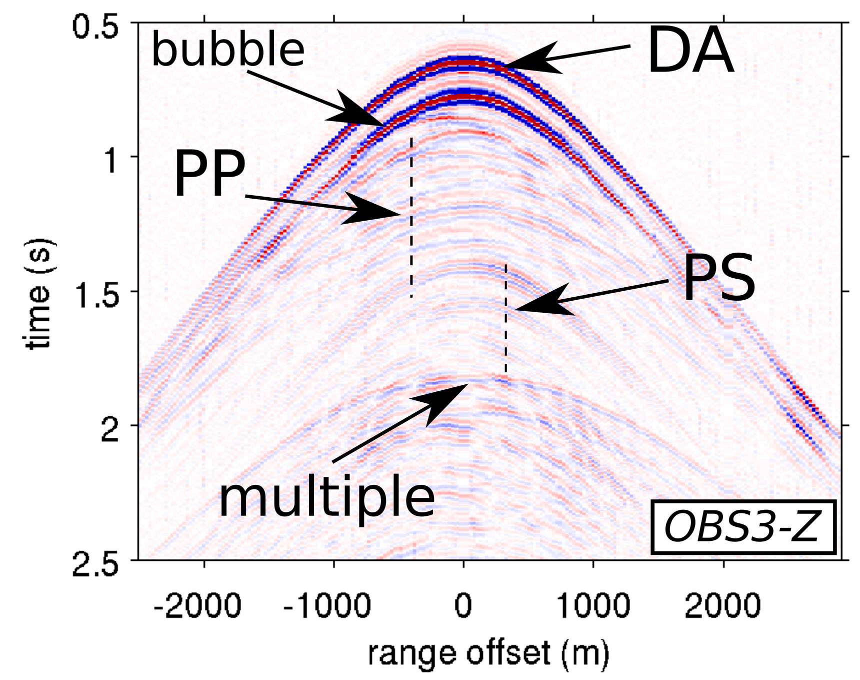


- Array processing introduces aliasing if working above the design frequency ($r > \lambda/2$)

OBS data

- 15 WHOI OBS deployed at the Woolsey Mound (Northern Gulf of Mexico) at 900-m water depth for a few days.
- GI gun towed above the OBS line, shooting every 25 m (April 7, 2011)
- new shot every 10–15 s.



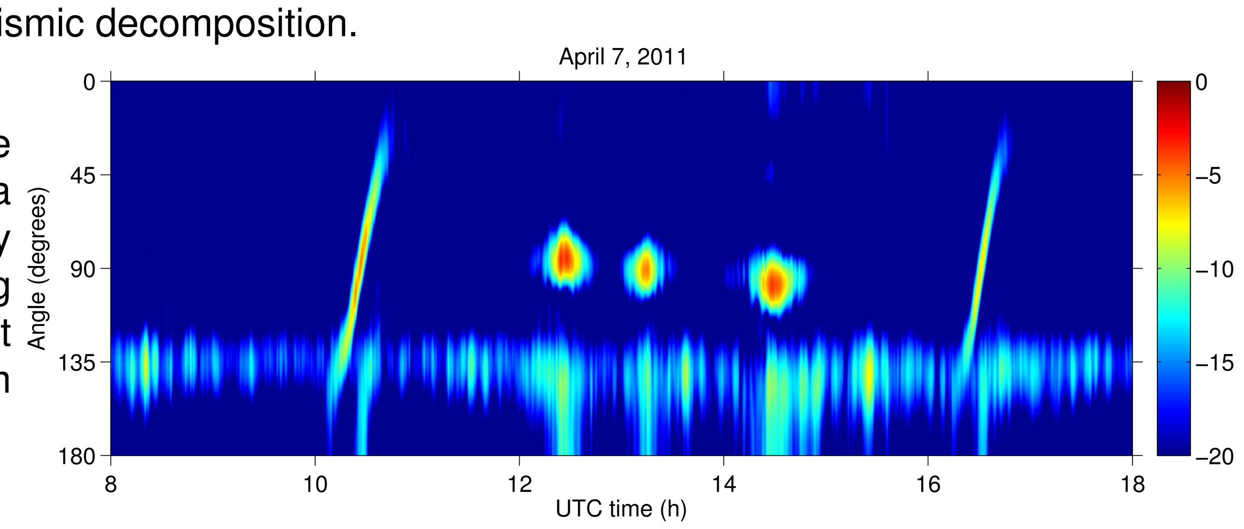


Crosscorrelation of different OBS components enables to extract different types of waves:

- hydrophone (P) and/or vertical geophone (Z) → PP
- vertical geophone (Z) and horizontal geophone → PS
- horizontal geophone → SS

Bubble pulse is removed from the signals using the downgoing wavefield estimated from an upgoing/downgoing seismic decomposition.

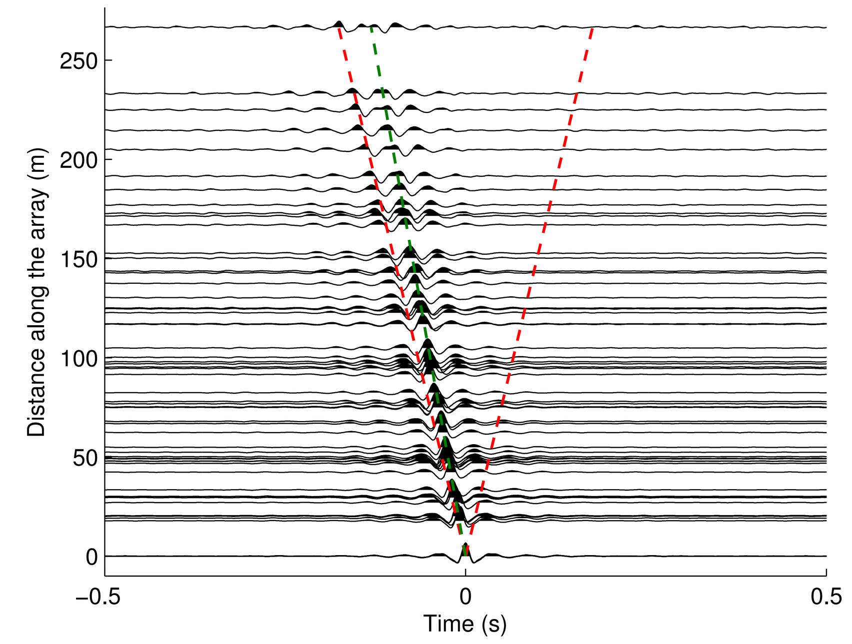
As revelead by the beamformer output, a distant seismic survey was present during the whole deployment at azimuth 135° from north.



Noise crosscorrelations

- 52h of noise data available
- Noise crosscorrelations (pressure) are dominated by a distant seismic survey

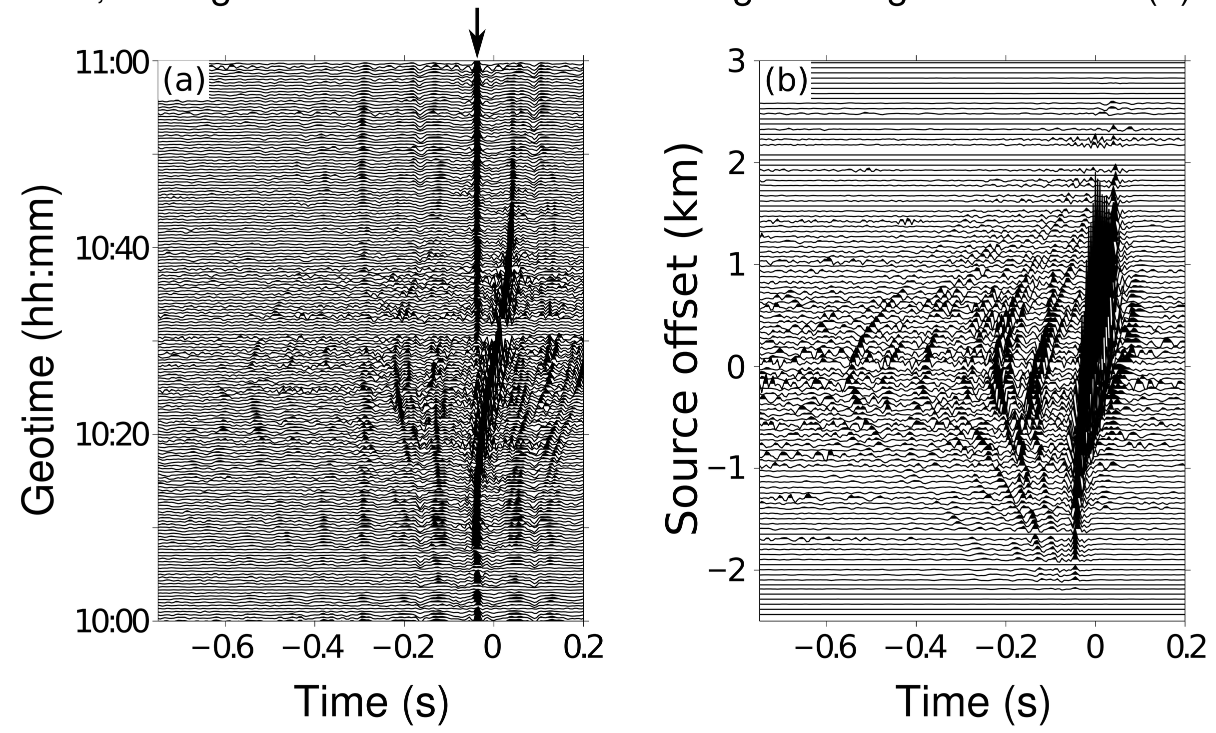
Theoretical direct arrival (red) and corrected direct arrival (green) using the estimated azimuthal angle of the distant noise source.



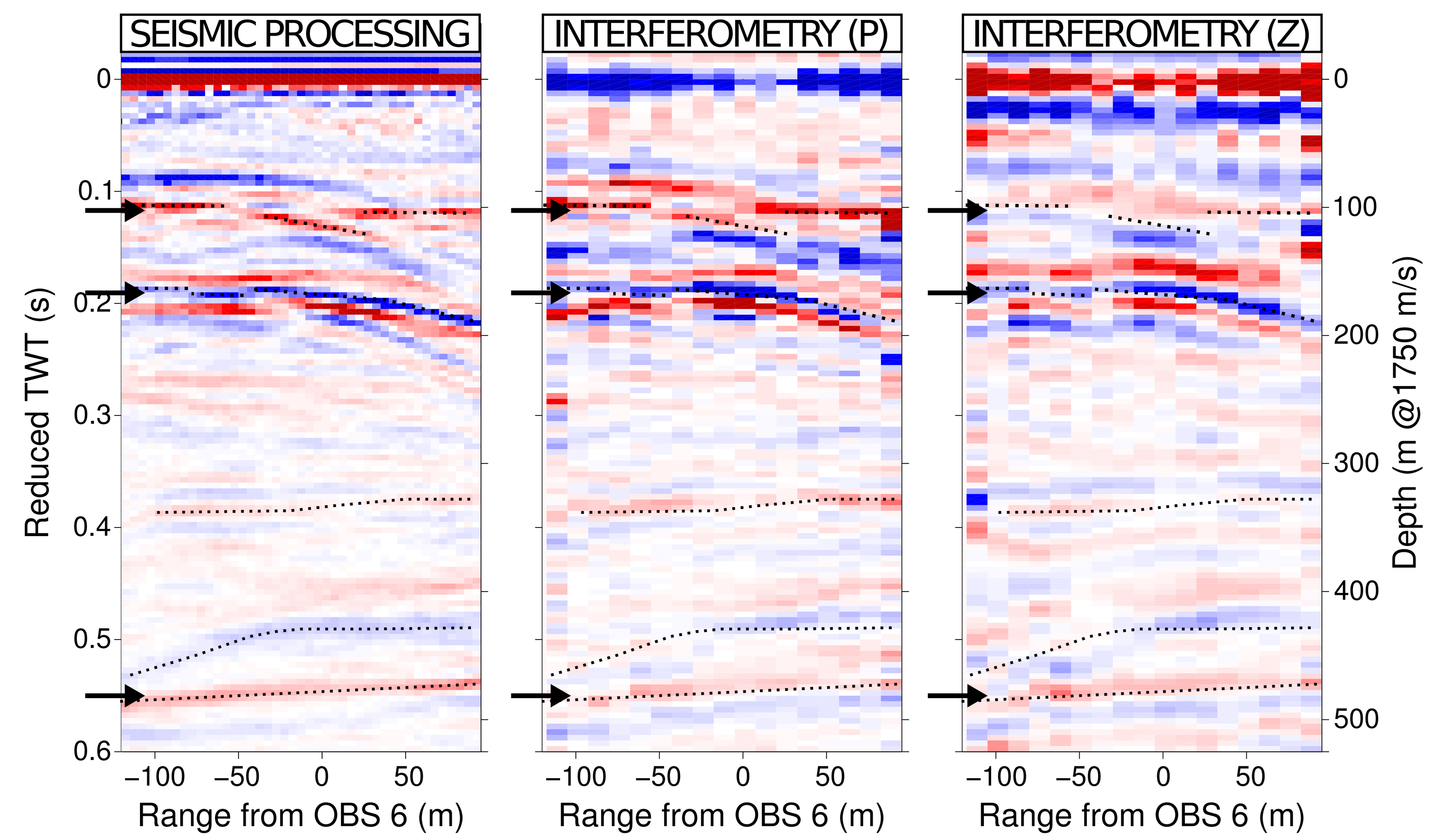
PP interferometric imaging with active data

With unknown shooting times, the signals are crosscorrelated using a sliding time window (a).

Time windows based on shooting time reduces the effect of other interfering sources (b). They are further attenuated by keeping only the direct arrival (time gate) on one of the signals before crosscorrelation.



Assuming horizontal layering, all extracted Green's function are migrated and stacked at their midpoint. Moveout is compensated for with a subsurface velocity model.



PP reflectivity immediately below the OBS array.

References

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