Towards 3D Noise source location using Matched Field Processing

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Abstract

Matched Field Processing (MFP), initially developed in ocean acoustics, is an array-processing and beamforming method, that locates noise sources in range, depth and azimuth. In this study, we analyze the sensitivity of MFP for 3D source location on the exploration scale in applied geophysics and discuss its **"acoustic" approximation compared to the "elastic/ correct" one** in a heterogeneous Earth.

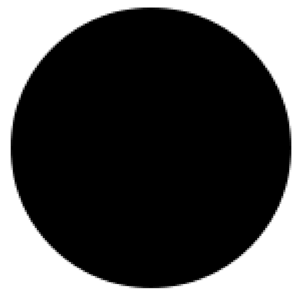
We computed synthetic array data sets in homogeneous and heterogeneous media with changing source distributions, source mechanisms and array configurations using **Finite Difference modelling** and inverted them with MFP. This allows to quantify the location uncertainties of the method and its performance regarding different geophysical problems.

To test our synthetic calculations, we applied **MFP to a real-world data set from the Gorner Glacier (Switzerland)**. The measurement took place in 2007 using a small and dense aperture array (6 stations, Ø < 500 m). The dominant noise source can be linked to a vertical englacial meltwater channel **(glacier moulin)**, neighbouring maxima might be caused by ice quakes or englacial water tremor sources. Snapshots from a **time-lapse analysis** of one day show, that the source activity is variable in space and time, as expected from melt-induced tremor sources.

Gorner Glacier

Figure 3 Gorner Glacier in Switzerland (location indicated with black cross on the map).

Explosion source



Explosion sources were modelled in homogeneous and heterogeneous media to investigate the sensitivity of MFP. MFP provides a correct source location and stable performance for single Explosions (Fig. 1A), multiple Explosions (Fig. 1B), as well as for Explosions situated outside the instrumental array considering smearing effects (Fig. 1C).

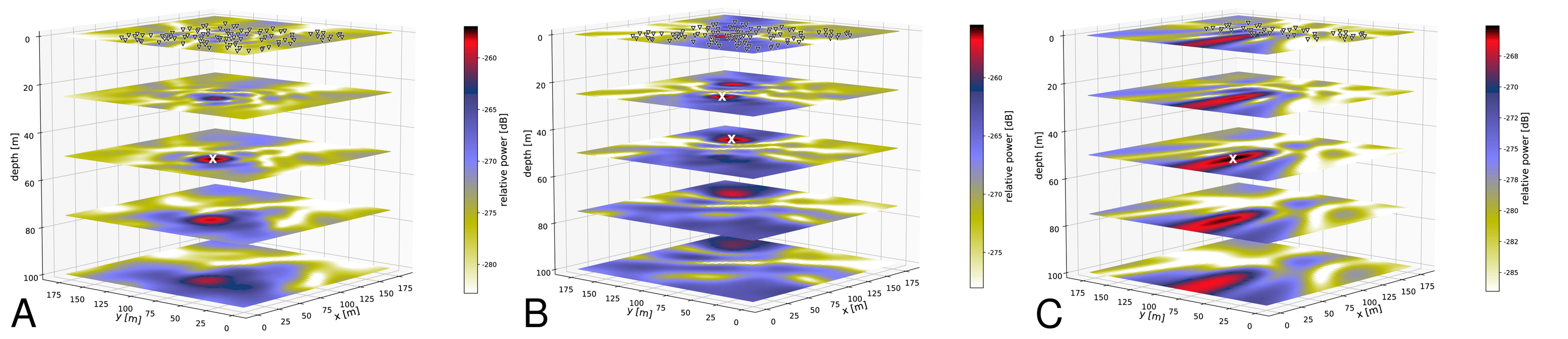


Figure 1 MFP inversions of synthetic Explosions modelled in a 3D heterogeneous environment with high velocity layers above the sources. The white crosses indicate the positions of the synthetic Explosions, the Bartlett output represents the source distribution by relative power values [dB]. **A** single Explosion. **B** two Explosions. **C** Explosion outside the array.

Matched Field Processing

field data (elastic)

$$K_{ij}(\omega) = d_{i,k}(\omega) d^*_{j,k}(\omega)$$

cross spectral density matrix

synthetic data (acoustic approximation)

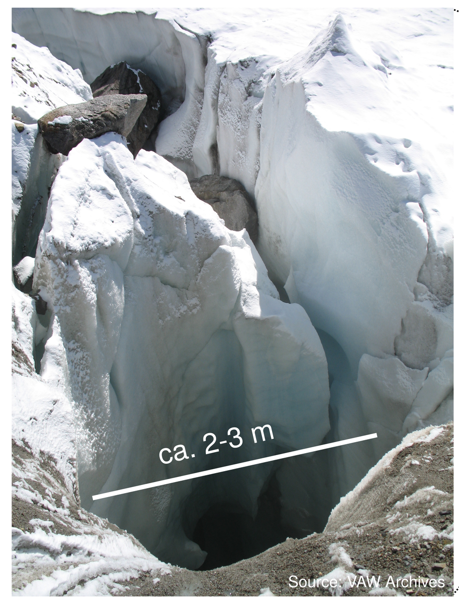
$$\hat{d}(\omega, a_i) = exp(j\frac{\omega a_i}{c})$$

replica (Green's function)

$$B(a) = \sum_{\omega} |\hat{d}^*(\omega, a_i) K_{ij}(\omega) \hat{d}(\omega, a_i)|$$

Bartlett processor

A temporary array (6 stations, Ø < 500 m, Fig. 4) was installed on the Gorner Glacier (Switzerland) in 2007. Here, we present source location beneath and in the close environment of the array using Matched Field Processing. Three snapshots from a time-lapse analysis of one day (07.07.2007, Fig. 5) show the location and variable temporal activity of a glacier moulin and neighbouring maxima (e.g. ice quakes, englacial water tremors).



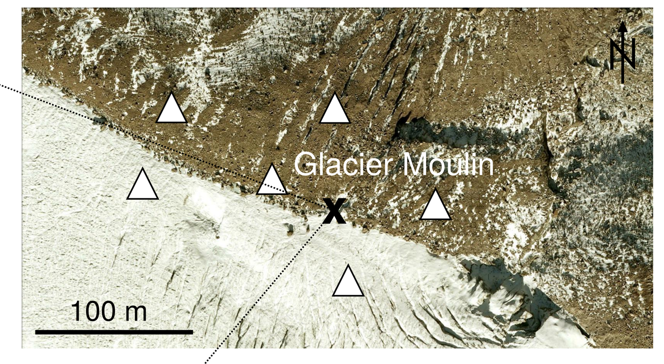
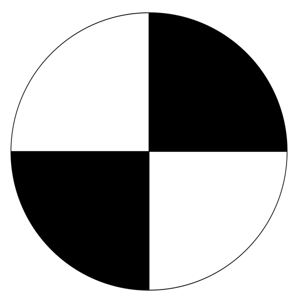


Figure 4 Array configuration on the Gorner Glacier. The white triangles indicate the positions of the 6 stations; the black cross shows the position of a glacier moulin within the array.

Double Couple source



Double Couple sources are characterized by compressional and dilatational motion resulting in + and - polarity of amplitude onsets depending on the azimuthal direction of the station relative to the source. Our first attempt to locate the Double Couple with conventional MFP failed (Fig. 2A).

We developed an approach that "corrects" the polarity pattern of a Double Couple source. Iteratively, seismic traces will be inverted, if it leads to a higher beampower. That allows us to deal with the Double Couple as we do with an Explosion (phase matching). This is convenient and approvable since we keep the general phase/ amplitude information of the signal. The polarity switch leads to a higher absolute sum of the beampower and a correct location of the source. The result is displayed in Fig. 2B.

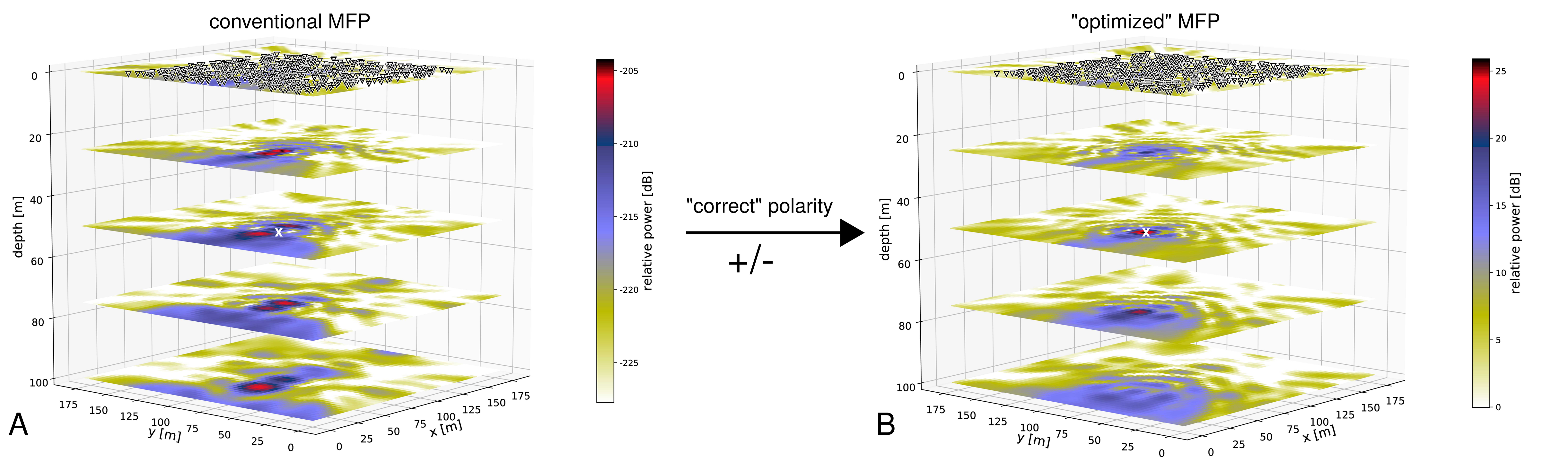


Figure 2 MFP inversions of synthetic Double Couples (xz) modelled in a 3D homogeneous environment. The white crosses indicate the positions of the synthetic double couples, the Bartlett output represents the source distribution by relative power values [dB]. **A** conventional MFP location. **B** optimized MFP location.

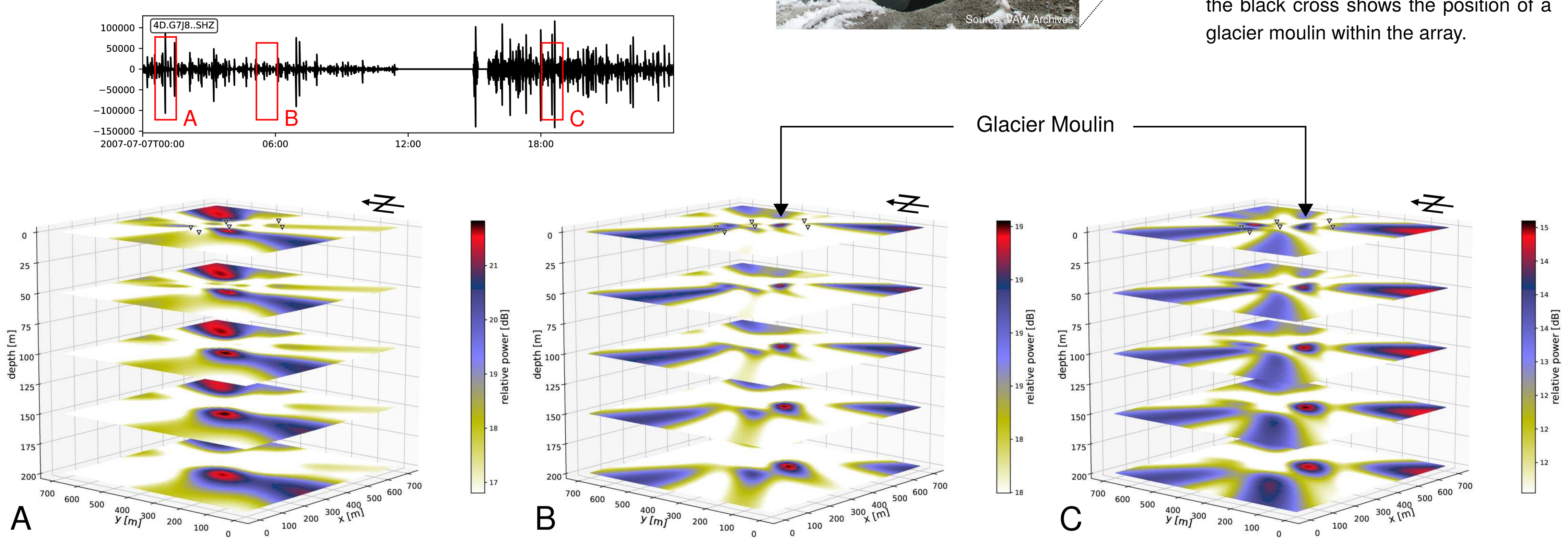


Figure 5 Snapshots from MFP time-lapse computation of 1 day (07.07.2007) in the the frequency range of 8-12 Hz.

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