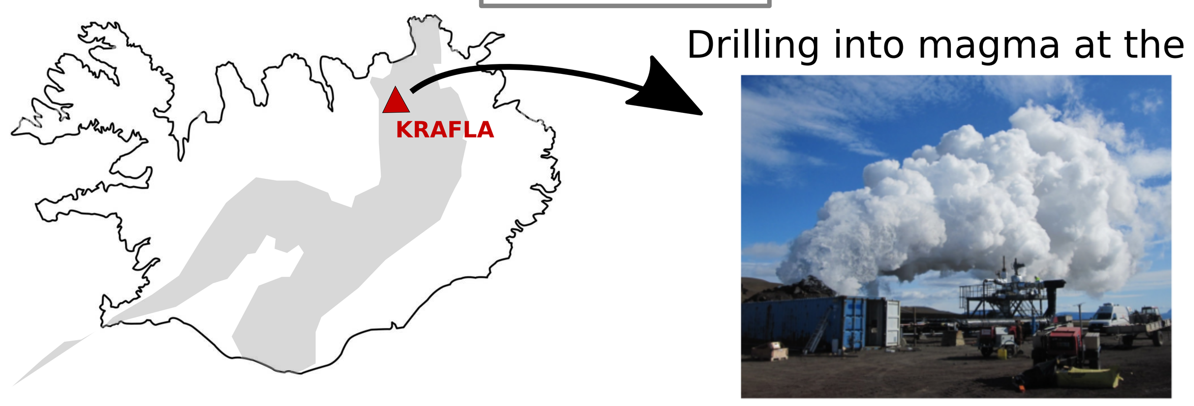
Near-surface effects in seismic wavefields at Krafla volcano (NE Iceland): characterization and mitigation.

Contact: maass@cp.dias.ie

Regina Maass[1], Christopher J. Bean[1], Ka Lok Li[1]

[1] Dublin Institute for Advanced Studies, Dublin, Ireland

SETTING



> Krafla: volcano caldera in NE of Iceland (diameter 10 km).
> Area used for geothermal energy exploitation.
> 2009: unexpected drilling into magma at 2.1 km depth (1.48 km b.s.l.) at IDDP1 borehole.
> Despite numerous studies, magma body undetected before drilling.

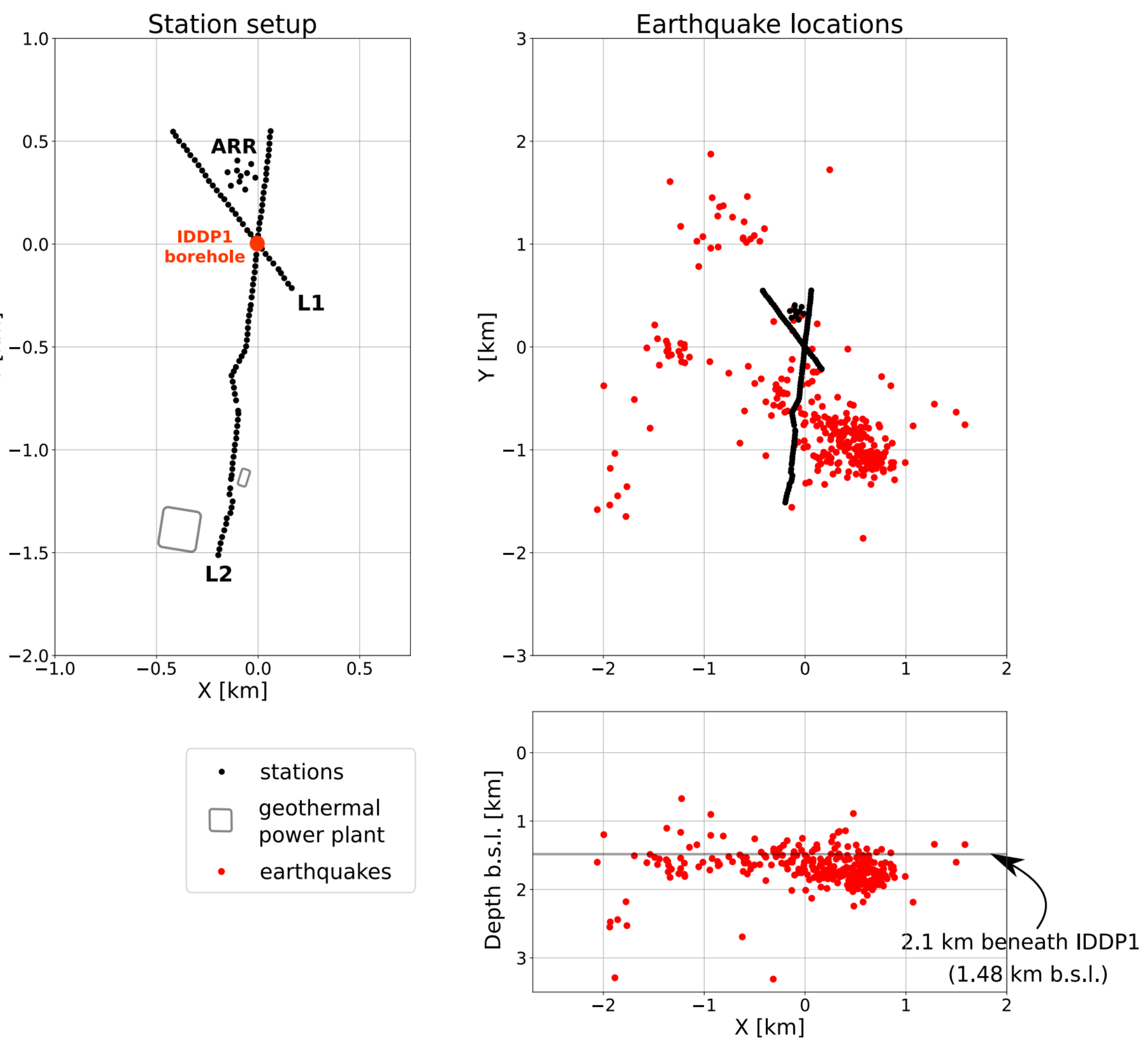
PROJECT GOAL

> **Improve earthquake reflection imaging in heterogeneous media.**

> Krafla provides unique setting because location of the magma pocket is known through drilling.

> How do we have to process complex seismic data to extract reflections from the magma pocket beneath the IDDP1?

STATIONS AND SEISMIC SOURCES

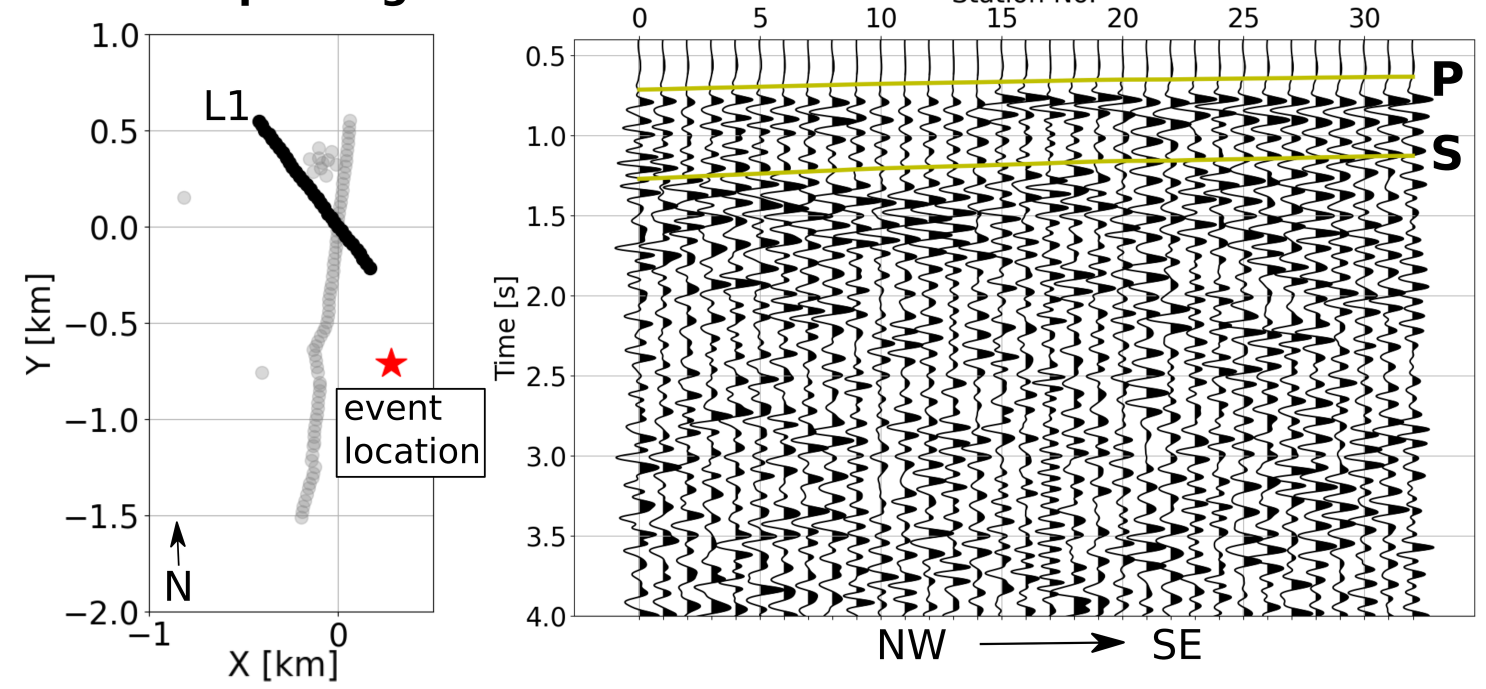


Stations: > 2 "reflection profiles" (**L1, L2**) that intersect at IDDP1 borehole. Interstation distance 30m.
> 1 "antenna" (**ARR**) for beamforming. Aperture 150m.

Sources: > More than 300 local earthquakes (M < 1.5).
> Industrial noise (> 1 Hz) generated by geothermal power plant.

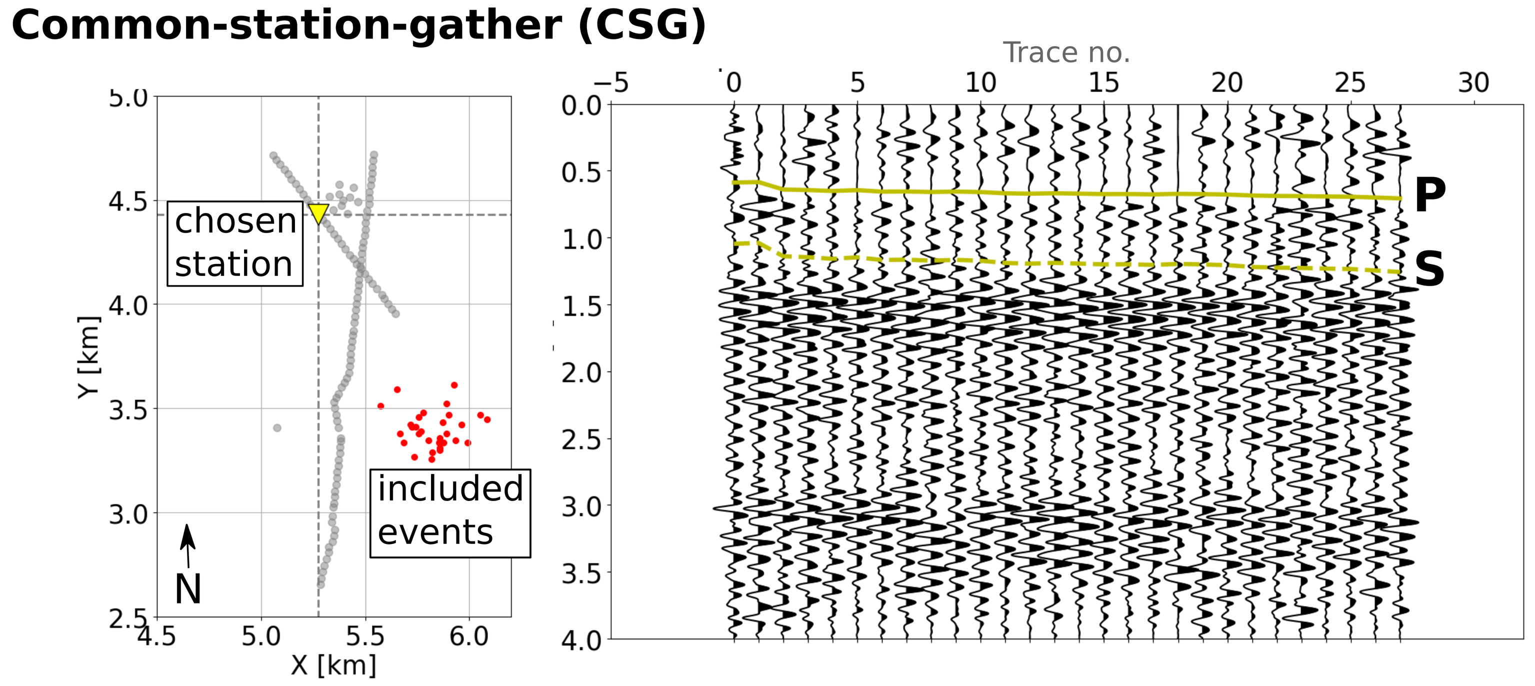
THE CHALLENGE: SITE EFFECTS

Common-quake-gather



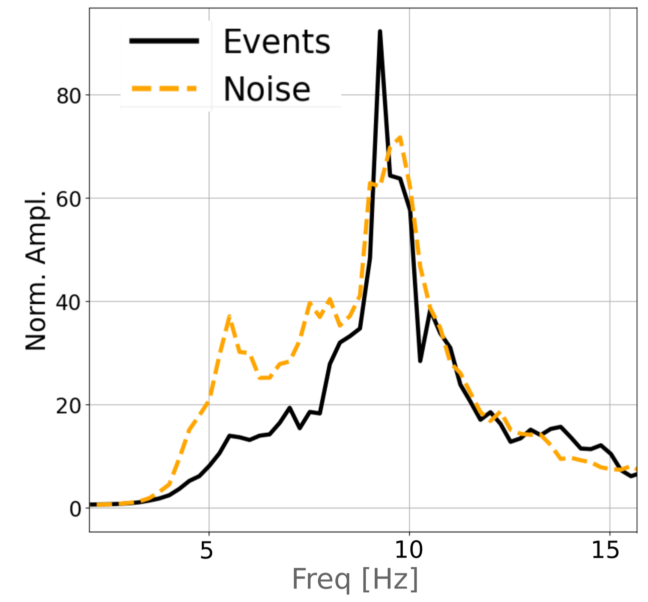
> Example for wavefield due to earthquake (M = 1.2).
> Z-component records of all stations of profile L1 are shown.
> Direct P and S waves clear, lack of coherency in S wave coda.
> Recorded waveforms are dominated by site/near-station effects.

Common-station-gather (CSG)



> Data in common-station domain more coherent.
> This is because all analysed traces share the same site effect.
> Coherent phases visible in S wave coda (e.g., at 3 seconds).
> Time series have monochromatic character.

- Black line: average of fourier spectra of all earthquake traces in CSG.
- Yellow line: same, but for 4s long noise window prior to each event.

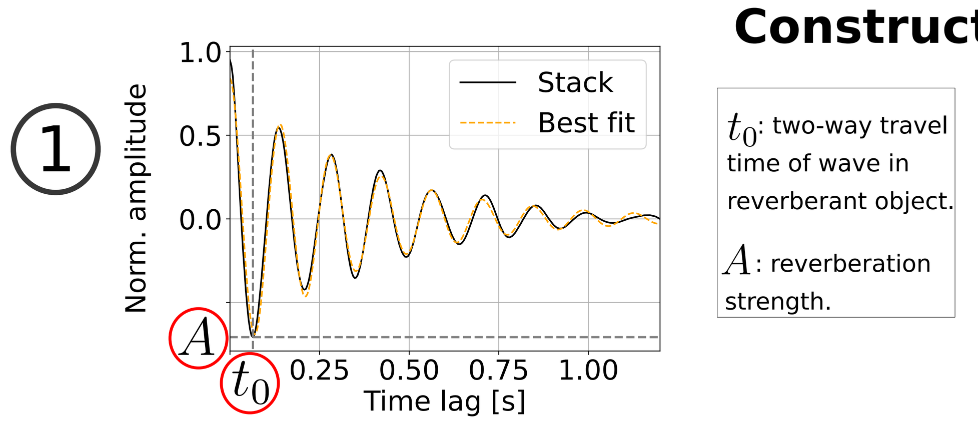


> Strong resonance peak at approx. 9 Hz in both event and noise spectra.
> Caused by wave reverberations within the upper few meters beneath the station (e.g., in lava cave).

CAN WE REDUCE SITE EFFECTS IN DATA?

Construction of resonance removal filter

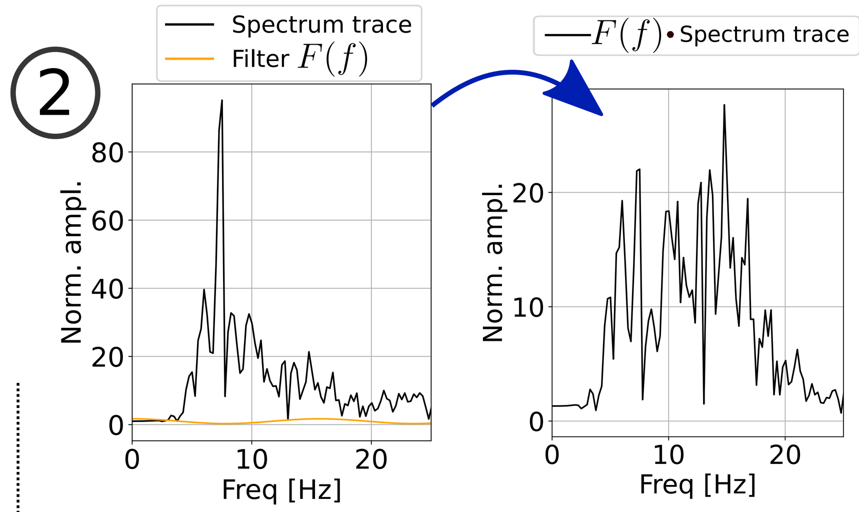
(1)



t_0: two-way travel time of wave in reverberant object.
A: reverberation strength.

> Compute autocorrelations of all traces in CSG.
> Stack all autocorrelations.
> Fit sine curve into stack.
> Pick parameters t_0 and A in fitted curve.

(2)



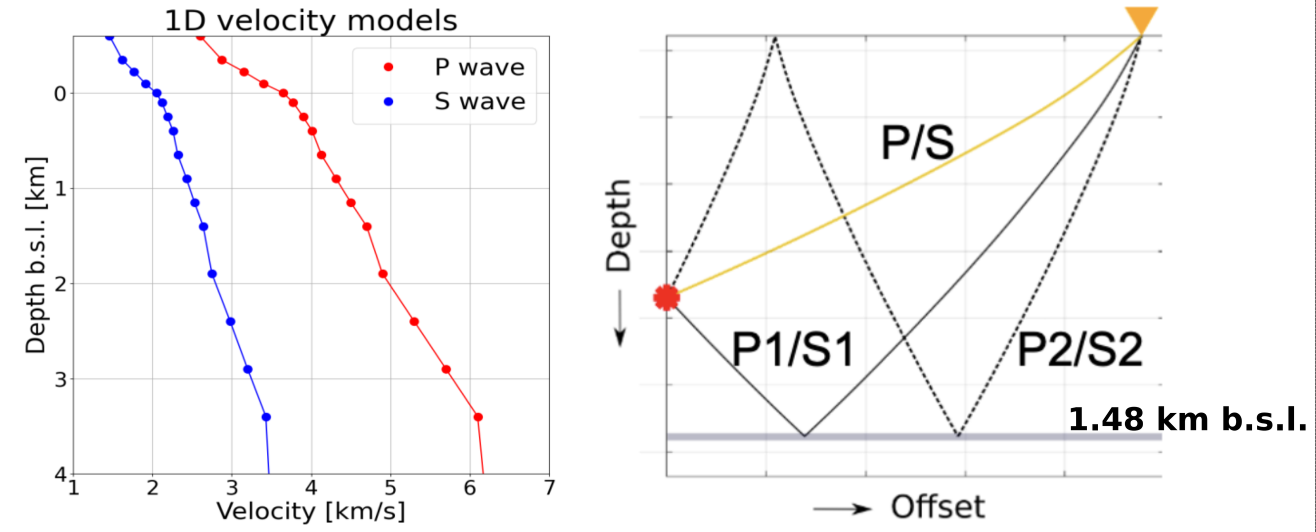
$$F(f) = 1 + Ae^{-2\pi i f t_0}$$

> Construct filter $F(f)$ in frequency domain.
> Multiply $F(f)$ with fourier spectrum of each trace in CSG.
> Compute inverse fourier transforms.

Stack of autocorrelations characterizes resonance --> can be regarded as part of the transfer function of the near-surface below station.

→ Applying the filter deconvolves reverberations/resonance from wavefield.

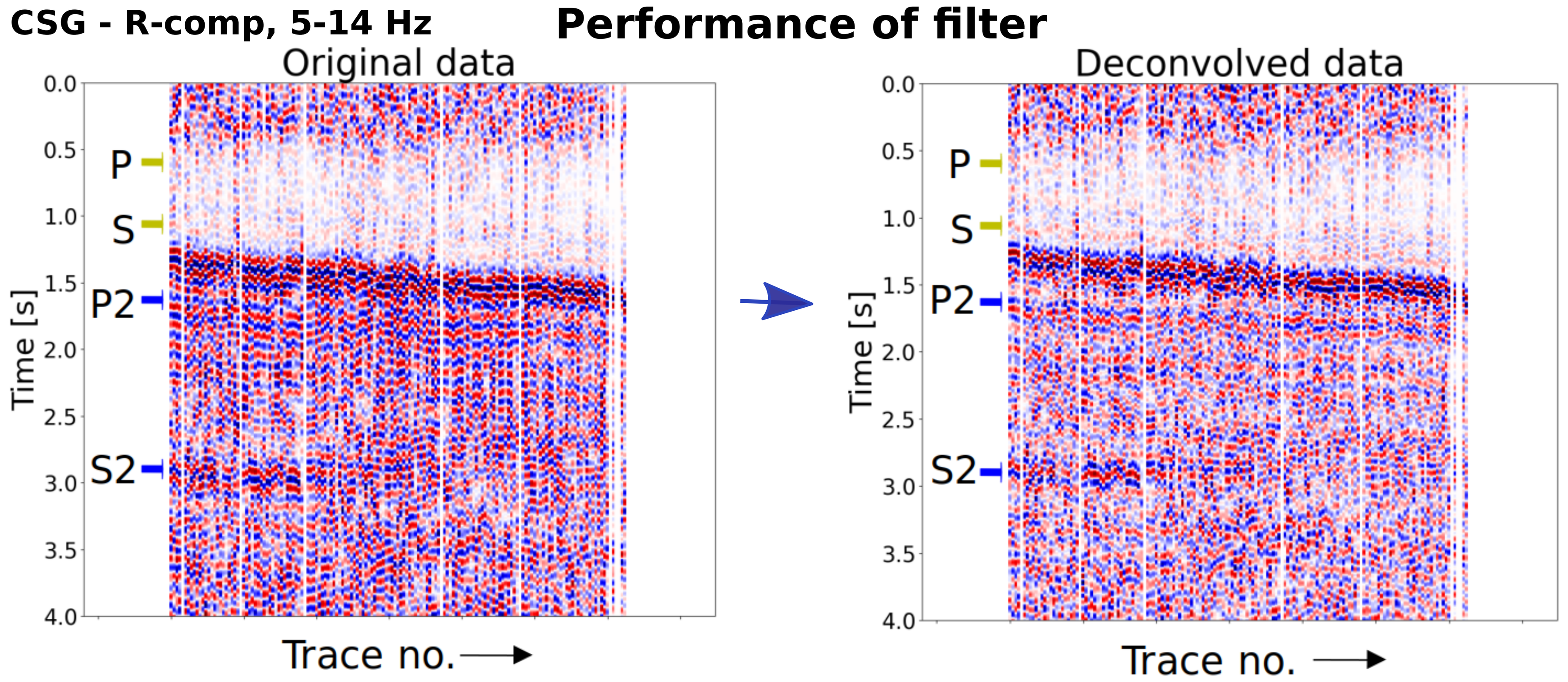
Raytracing



Using 1D velocity models for P- and S waves provided by ISOR, we compute theoretical traveltimes for direct P and S waves as well as for reflections (S1/P1/S2/P2). We do not consider conversions here.

Performance of filter

CSG - R-comp, 5-14 Hz



> Strong reverberations following the S wave arrival in the shown CSG.
> Coherent phase visible at 3 seconds that fits with expected arrival time for S2.

> Reverberations considerably reduced.
> Coherent phase at 3 seconds sharper.
> New coherent phase at 1.6 seconds at expected arrival time for P2.

TAKE AWAY POINTS

Lack of coherency in seismic data at Krafla
> Due to dominance of site effects in wavefields.
> Makes reflection seismic imaging very challenging.

Site effects constrained in common-station-domain
> Data more coherent in common-station-gather (CSG).
> Site effect includes strong reverberations/resonance effects.

Part of site effects can be deconvolved from data
> Autocorrelation stack characterizes reverberations/resonance.
> Resonance removal filter deconvolves reverberations from data.
> Phases emerge in deconvolved data that were previously obscured.
> Phases potentially associated with reflections from magma body found at Krafla during drilling in 2009.

We suggest that the presented method can be applied generally in high-frequency data at volcanoes if strong reverberations are observed.

References

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