DAS Walkaway VSP Processing

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Content

Introduction

This tutorial is for the users who aim to apply **RadExPro** for the processing of walkaway vertical seismic profile (VSP) data acquired with distributed acoustic sensors (DAS). The tutorial is accompanied by a **RadExPro** project where the explained steps are present as processing flows. The processing flows in the tutorial project include correlation with sweep, geometry setup, noise removal, deconvolution, wavefield separation and migration.

The input dataset is a walkaway VSP survey with both DAS and geophones studied by Zulic et al. (2022) and published as an open-source dataset at Research Data Australia (https://doi.org/10.25917/7h0e-d392). This dataset was provided under a CC BY 4.0 license. More details can be found at https://creativecommons.org/licenses/by/4.0/. For the purposes of this tutorial, we extracted the sweep for correlation from the geophone SEG-Y and several offsets from the DAS SEG-Y for processing.

Data input and correlation with sweep

The flow **005-Sweep-Input** loads the sweep and saves it to a dataset. SEG-Y Input is used along with the Data Filter to select the sweep trace in the input geophone *2020_GeoLab_WVSP_Geophone_wgm.sgy* file and Trace Output saves it to *001-sweep* dataset.

The flow **010-Data-input-and-correlation** conducts data input and correlation with the sweep. We load the DAS VSP file *2020_GeoLab_WVSP_DAS_wgm.sgy* with SEG-Y Input and immediately correlate it with the sweep with the Custom Impulse Trace Transform and cut it to the maximum time of 2 seconds with Trace Length in order to save storage space. The parameters for Custom Impulse Trace Transform are shown below. The uncorrelated dataset is given to the module through the flow, the *001-sweep* is specified in the *Parameters of the wavelet* window. To conduct crosscorrelation, we choose *Multiply* in *Amplitude spectra parameters – Operation* and *Subtract* in *Phase spectra parameters – Operation.*
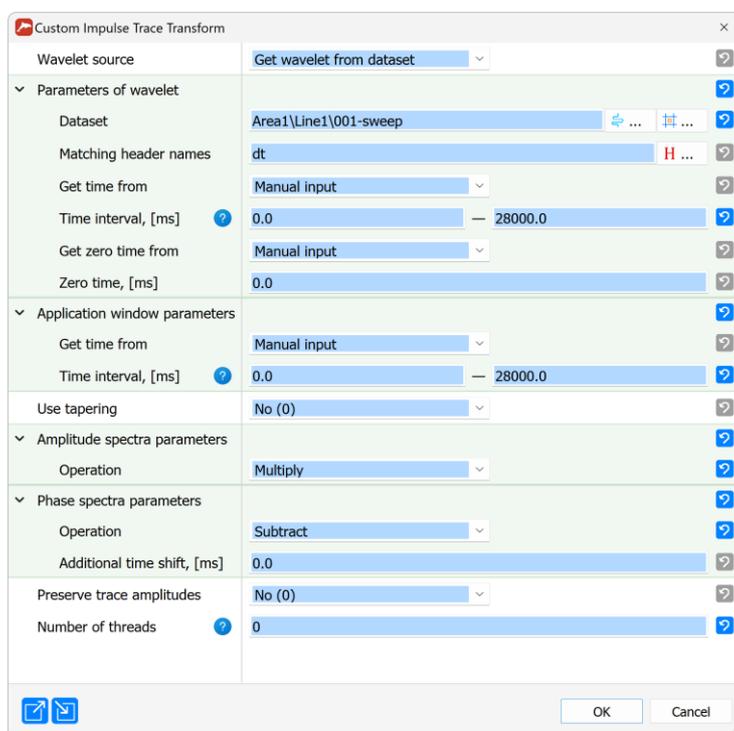
Custom Impulse Trace Transform module parameters

The flow **020-Data-selection** is auxiliary – it just numbers the shot points sequentially and puts the numbers in the SOU_SLOC header (there are no shot point numbers in the headers of the original file) and filters out the repeated shots (there are shot duplicates in the dataset), leaving only one set of traces for each shot point. Also, here we select the 16 shots closest to the well for further processing.

Geometry setup

The input SEG-Y files have the source and receiver coordinates in place. However, for completeness, an example of geometry setup which works for this dataset is provided in the **025-**

Geometry flow. The geometry setup is performed by the VSP Geometry* module with the following parameters.

VSP Geometry module parameters*

Inclinometry is not provided, so the well is assumed to be vertical, its wellhead coordinates are input in *Well X, [m]* and *Well Y, [m]* fields. The wellhead, datum and zero level for the depth header are assumed to be at the Earth's surface, so the altitudes in the *Receiver geometry* section are set to 0.0. Source coordinates and elevations are provided in the *Source-coordinates-radex.txt* file, which is located in the project's Data directory. The file is tab-separated and contains the shot point ID (in this case, the SOU_SLOC header we filled in previously), the X and Y shot coordinates and their elevations. The first few lines of the file look as follows.

SOU_SLOC	X	Y	Elevation
1	395103.5	6457953	0.4
2	395103.3	6457963	0.6
3	395103.9	6457974	0.6
4	395104.3	6457984	0.7
5	395104.6	6457994	0.6
6	395105.1	6458004	0.5
7	395105.5	6458014	0.5
8	395106.1	6458024	0.5

An example of a source coordinate file

The module uses the provided data along with the DEPTH, CHAN and COMP headers to fill in SOU_X, SOU_Y, SOU_ELEV, REC_X, REC_Y and REC_ELEV.

Denoise

The flow **030-Denoise** removes the DAS instrument noise. This type of noise is related to the interrogator device, so it exhibits itself as constant-time horizontal events on the seismic gathers highlighted with red rectangles in the image below. In this dataset, the noise is quite weak, but we still provide an example of removing it. Application of the 2D Spatial Filtering module successfully removes this noise.
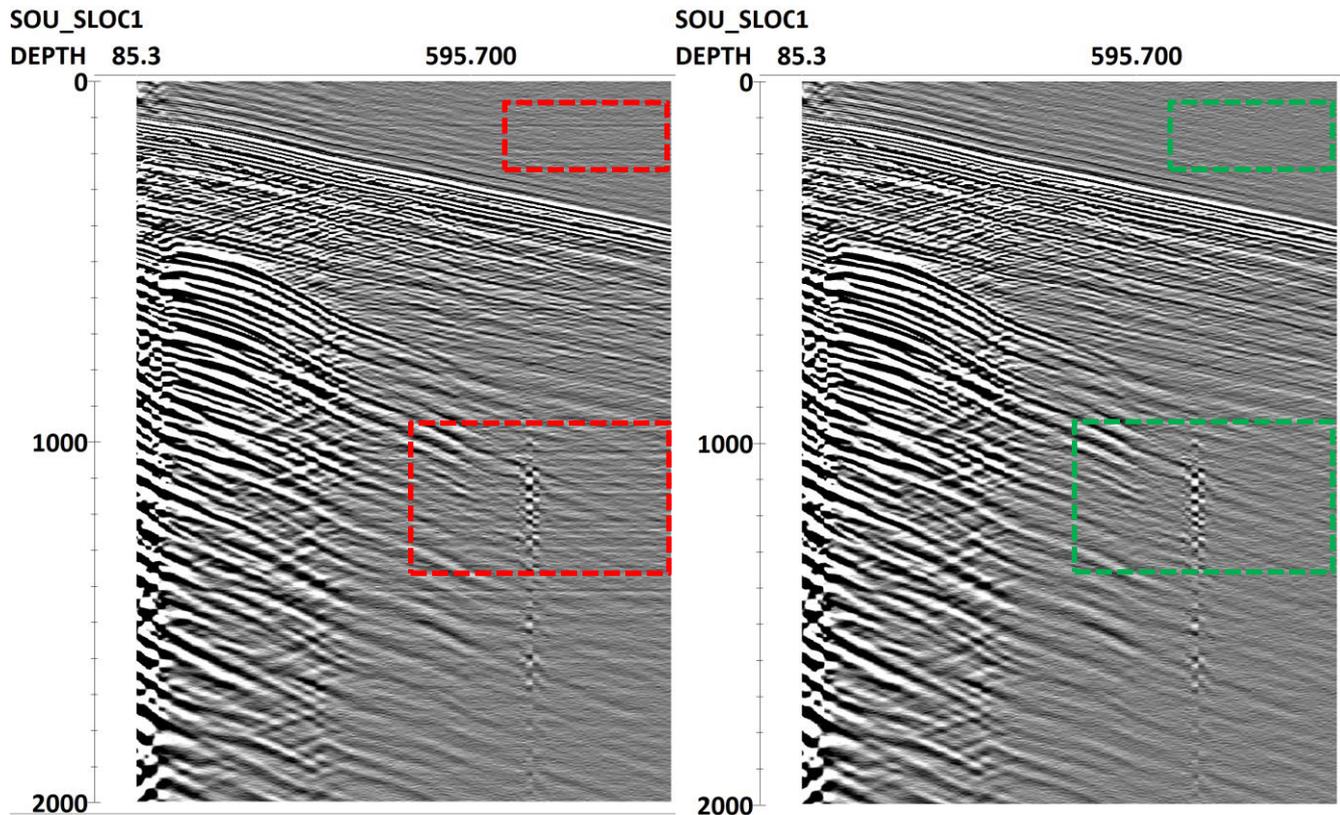
Seismic gather before (left) and after (right) noise removal

The parameters of 2D Spatial Filtering module are as follows. The noise is estimated by a median filter along trace axis and then subtracted using *Filter mode - Subtraction*.
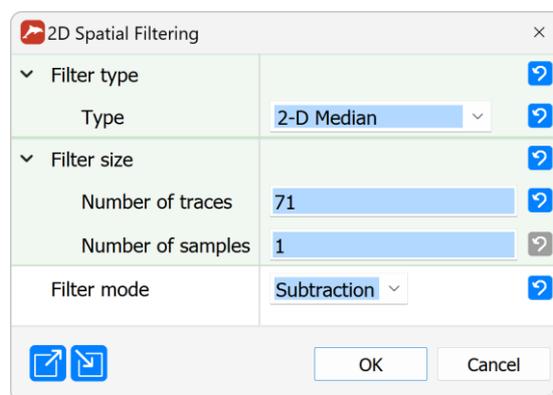
2D Spatial Filtering module parameters

Wavelet estimation

Next, we conduct the wavelet estimation for consequent deconvolution. There can be multiple

ways for wavelet estimation from VSP data, here we demonstrate the wavelet estimation by stacking first arrivals, which is one of the straightforward ways. Note that the applied workflow is not exactly accurate in terms of amplitudes, however it is suitable for the imaging we are conducting here. First, there is a flow called **035-First-break-picking**, which has Trace Input, Resample, Amplitude Correction and Screen Display modules. This section results in a display where one needs to pick the first arrivals. We picked the onset of the wavelet and saved it to database as *fbpick_shift*. This means that we are treating the wavelet as minimum phase (Dong et al., 2004), although the data is vibroseis, which is a mix between the zero-phase correlated signal and causal attenuation and scattering subsurface effects. For higher accuracy, one could convert the vibroseis signal to true minimum-phase before this procedure (Cambois, 2000).

After the first arrival is picked, we conduct the first arrival averaging in the **040-Wavelet-estimation** flow.

```
Generate wavelets
Trace Input <- 003-DAS-denoise
Amplitude Correction
Data Filter
Data Filter
Data Filter
Apply Statics <- fbpick_shift
2D Spatial Filtering
Ensemble Stack
Amplitude Correction
Trace Length
Trace Output -> 004-wav
```

Section of the flow which estimates the wavelets by first arrival averaging

This section first introduces the spherical divergence correction using Amplitude Correction with *Time raise to power = 1.0*, then selects the 180-500 m depth interval for averaging with a set of Data Filters, flattens first arrivals with Apply Statics, smooths the flattened arrivals with 2D Spatial Filtering and stacks them for each shot separately with Ensemble Stack. In Apply Statics, we set *Relative to time* to 100.0 so that the module places the wavelets' zero times at 100.0 ms for convenience of visualization. Next, the amplitudes of the wavelets are equalized with Amplitude Correction in Trace equalization mode, the wavelets are then cut to 400 ms with Trace Length and saved to the dataset *004-wav*.
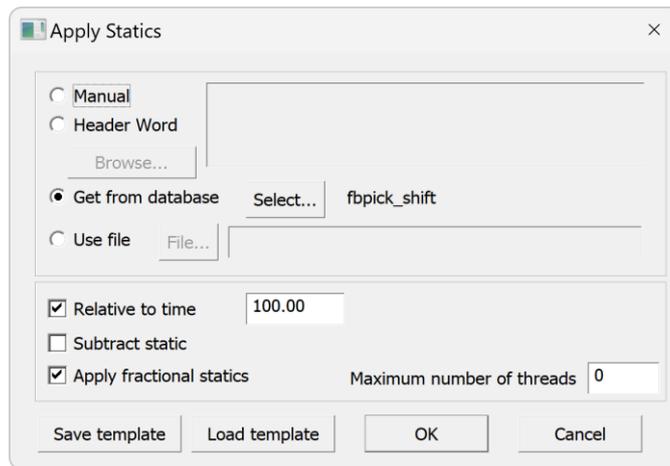
Apply Statics module parameters for flattening first arrivals
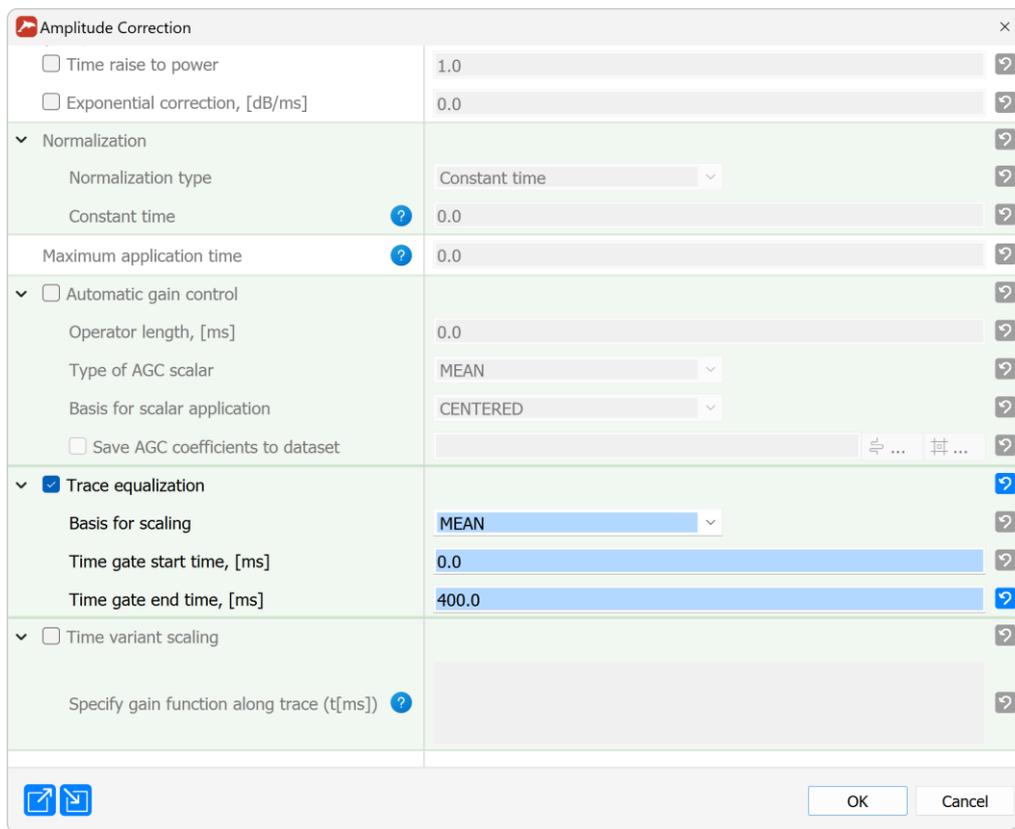
Amplitude Correction module parameters for wavelets' amplitude equalization

Estimated wavelets
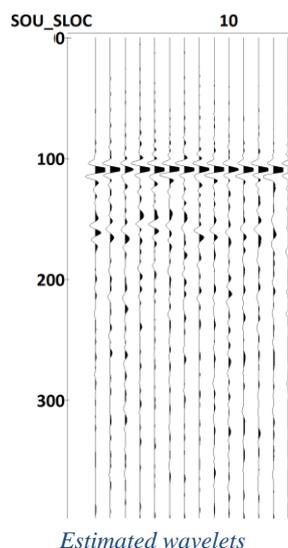
Wavefield separation

The **050-Wavefield-separation** flow uses the previously estimated wavelets for deconvolution and then separates out the upgoing wavefield for migration. It consists of three stages – deconvolution, upgoing wavefield separation and top muting.

Processing flow for deconvolution and wavefield separation

For the deconvolution, we first bottom-mute the high-amplitude S-waves with Trace Editing (the muting curve *botmut* is picked manually) to avoid deconvolution edge effects from these high amplitudes, then we conduct deconvolution with Custom Impulse Trace Transform, after which the bottom muting is reapplied. In the parameters of Custom Impulse Trace Transform, the wavelet dataset *004-wav* is specified with SOU_SLOC as matching header (to make sure each shot is deconvolved with its specific wavelet). The time interval for the wavelet is chosen to be 100-400 ms to take into account the 100 ms which were specified in the *Relative to time* parameter in the Apply Statics in wavelet estimation. To conduct regularized deconvolution, we choose *Divide* in *Amplitude spectra parameters – Operation* with *Damp = 0.4* and *Subtract* in *Phase spectra parameters – Operation*.
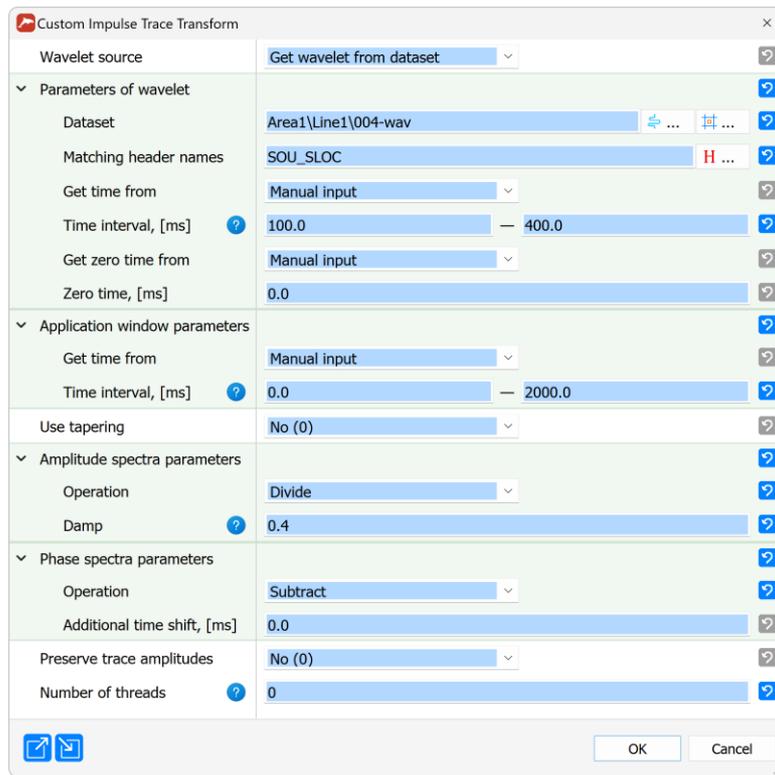
Custom Impulse Trace Transform module parameters for deconvolution

When comparing the VSP gathers before and after deconvolution, one can observe how the downgoing wavelets are compressed into an isolated pulse.
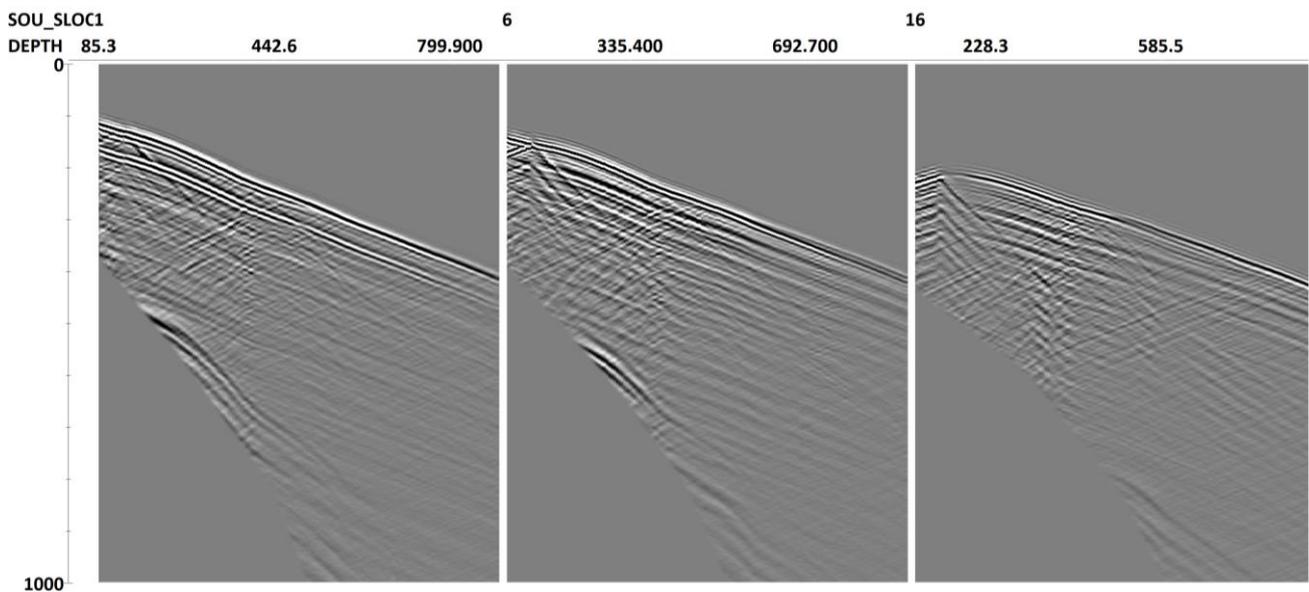
DAS gathers before deconvolution
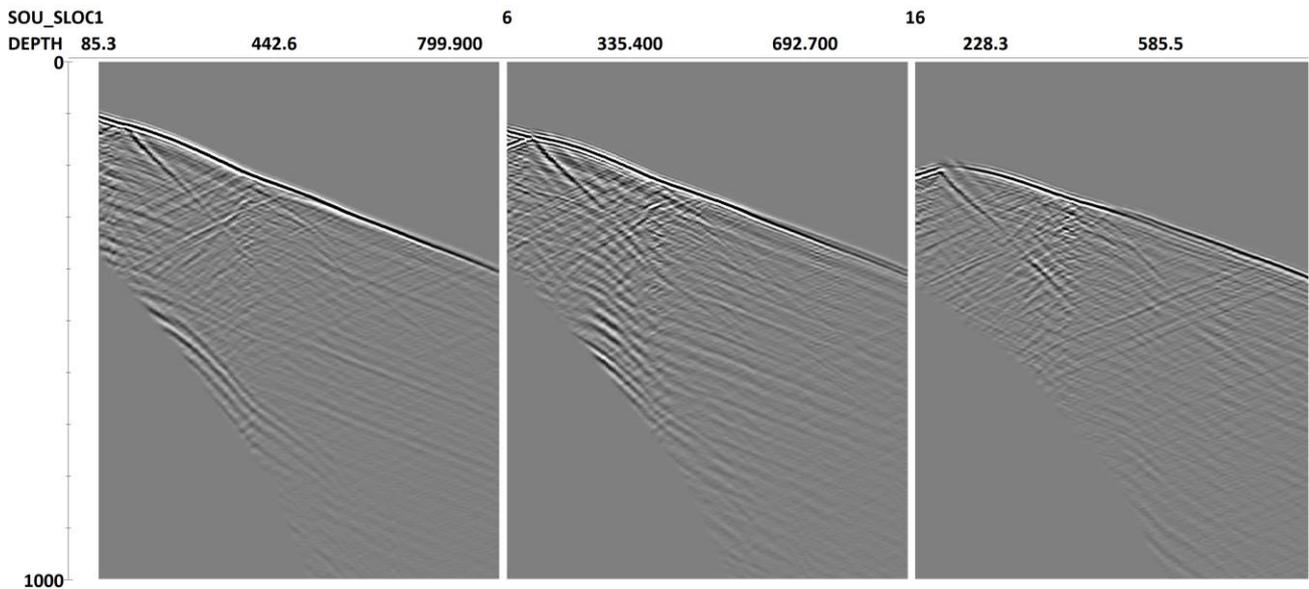
DAS gathers after deconvolution

Next, the flow conducts wavefield separation. Due to the small interval between the traces in DAS data, it is quite easy to separate out the upgoing wavefield just using the F-K Filter, as aliasing is not a problem. Notice how the F-K Filter is wrapped in Amplitude Correction and Remove AGC. Amplitude Correction applies Automatic Gain Control (AGC) to make the amplitudes more even in the data, which is useful for avoiding edge effects of 2D filters like F-K Filter. The amplitude effect of AGC is saved to a dataset called *agc*, which is used after the F-K Filter in Remove AGC to undo the amplitude changes of AGC.
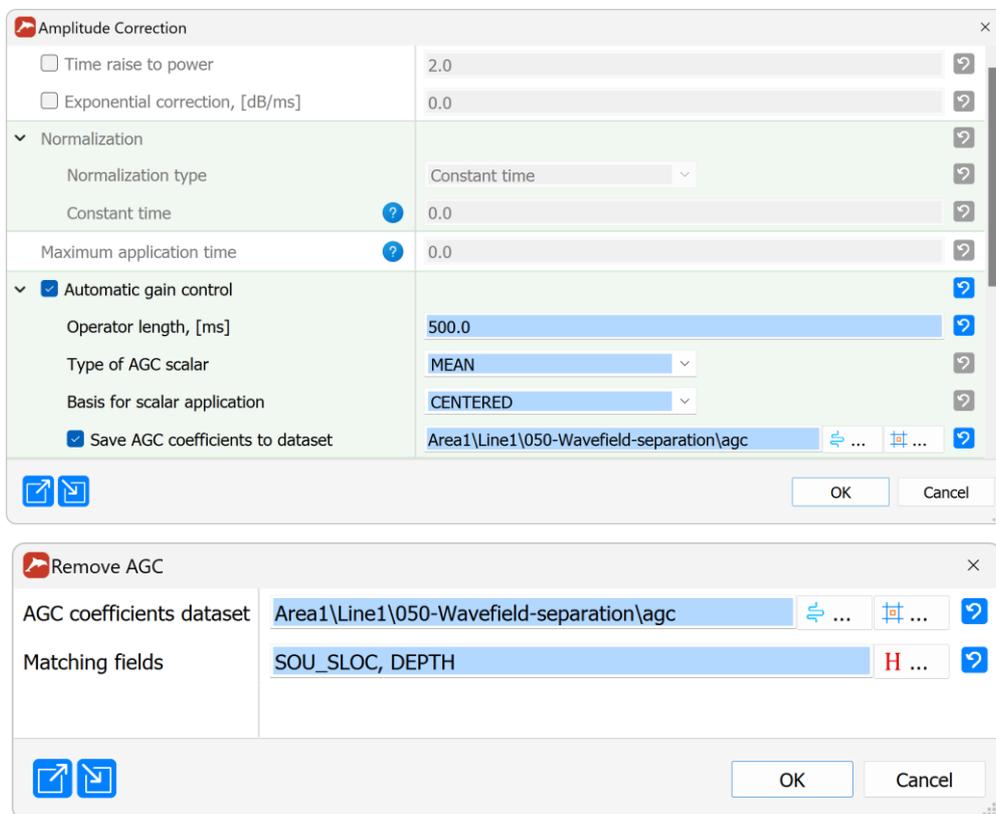

Amplitude Correction and Remove AGC parameters used to conduct AGC before F-K filter and then remove it

The F-K Filter parameters are shown below. We use the *Fan* filter in *Pass* mode, keeping only a range of velocities between -2000 to -4500 m/s, which is the range of velocities for reflected P-waves in the studied data.

F-K Filter parameters used to conduct upgoing wavefield separation

The last few modules in the flow conduct top muting of the result. SSAA puts the time in *fbpick_shift* to AAXFILT header in the data, which is then edited is Trace Header Math by subtracting 20 ms from it. AAXFILT is then used as a top muting curve in Trace Editing.
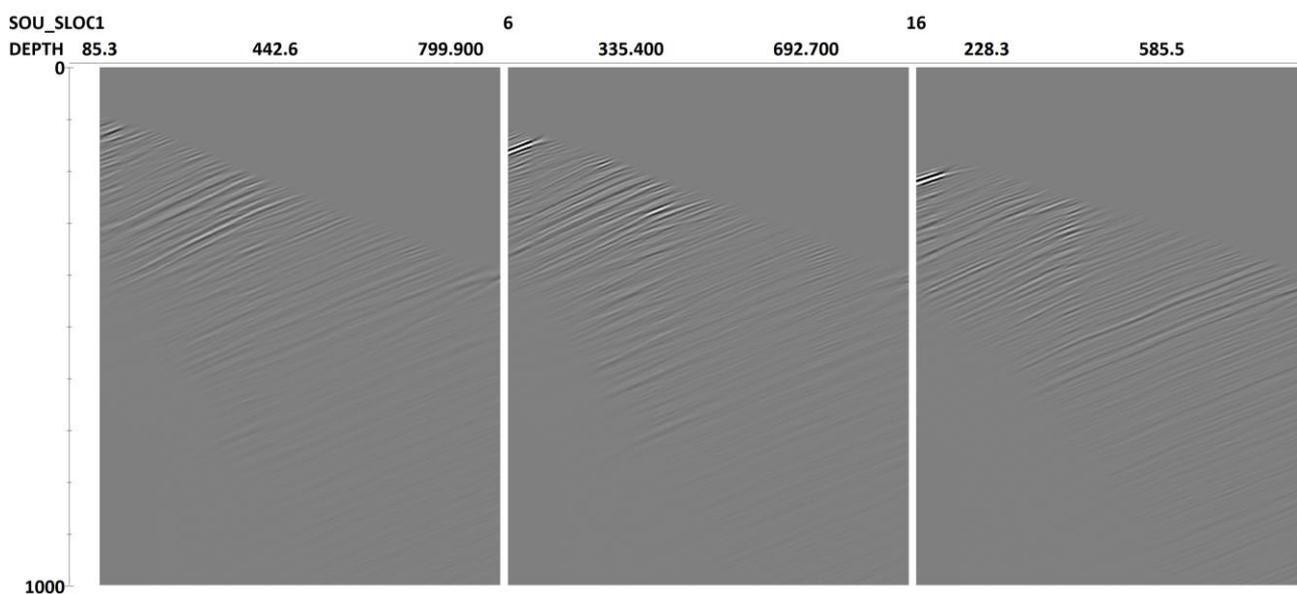

Upgoing wavefield extracted from DAS gathers

Velocity analysis

Before using the separated upgoing wavefield for migration, one needs to create a velocity model. Here, we use the Advanced VSP Display module to create a one-dimensional velocity model from the

first break picks on zero-offset data. We first output the smallest offset in the survey to a separate dataset in the flow **055-Zero-offset-selection**. In the **060-Velocity-analysis** flow, we input this dataset to Advanced VSP Display. We also make sure that the previously picked first breaks are written to the FBPICK header using the SSAA module. In the Advanced VSP Display, we divide the subsurface into layers when analyzing the velocity curve computed from first breaks (displayed in red to the left of the VSP gather). A new layer is created by left-clicking the window with the VSP gather on the depth where one needs to place a new boundary between the layers. After this, a velocity model is created, which is written to the file specified in the Advanced VSP Display parameters. In the Advanced VSP Display window, this layered velocity model is shown with a blue line to the left of the VSP gather.
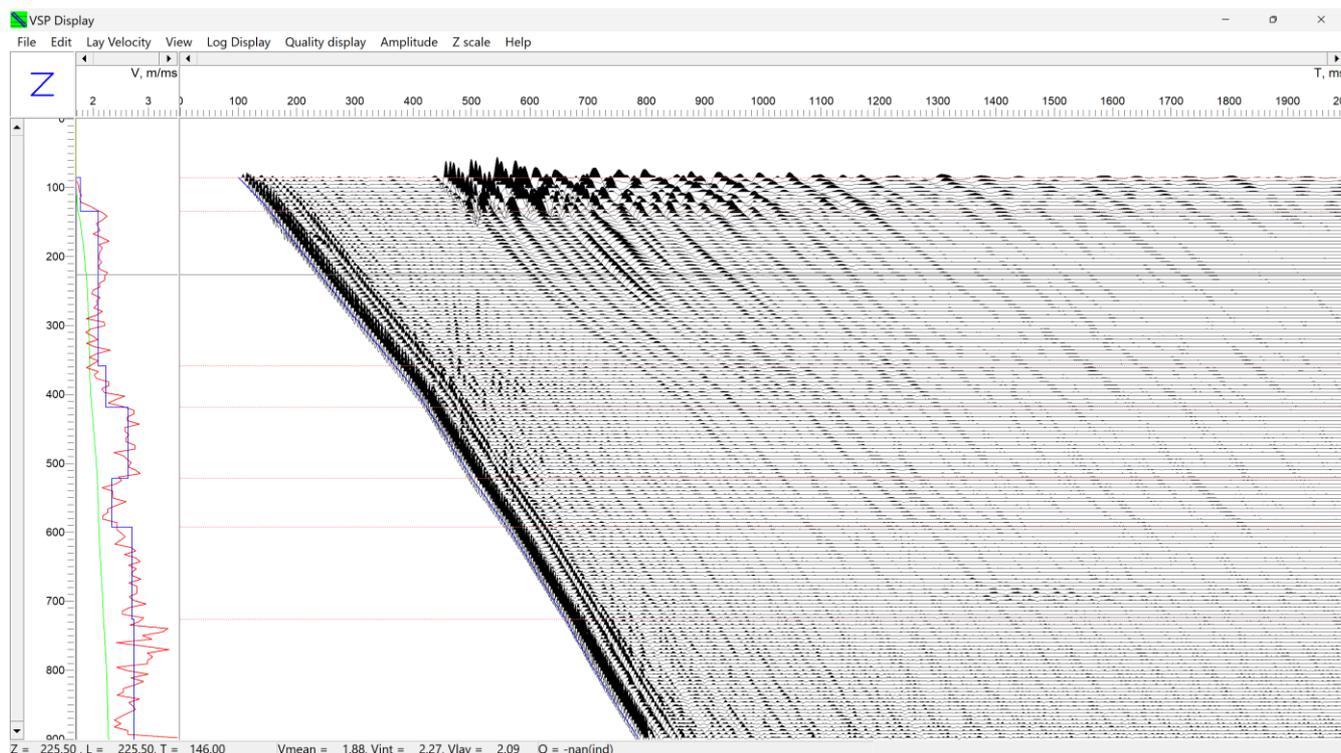
Advanced VSP Display

Migration

The final step of the workflow is the migration, which occurs in the **070-Migration** flow. In the migration parameters below, the migration grid is specified by a 0-900 m depth range with 2 m sample interval along depth and two end points of the migration profile (here, we picked the well coordinate and the coordinate of the last shot in the line) with 5 m sample interval along the line. Walkaway VSP weights are used with the '1/2 Derivative' option, which is a 2D migration rho filter. The area which is not illuminated by reflected rays in the given velocity model is muted with the 'Mute unaccessible area' option.

Migration parameters

The migration result with evident horizontal layering can be seen below.
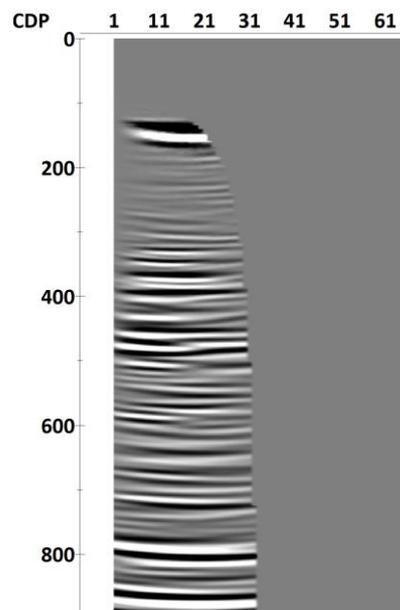
Migration result

References

Cambois, G. (2000). Zero-phasing the zero-phase source. The Leading Edge, 19(1), 72-75.

Dong, L., Margrave, G., & Mewhort, L. (2004, October). Examining the phase property of the nonstationary Vibroseis wavelet. In SEG International Exposition and Annual Meeting (pp. SEG-2004). SEG.

Zulic, S., Sidenko, E., Yurikov, A., Tertyshnikov, K., Bona, A., & Pevzner, R. (2022). Comparison of amplitude measurements on borehole geophone and das data. Sensors, 22(23), 9510.