INFLUENCE OF A SCATTERING SURFACE LAYER ON LOCALIZATION ACCURACY BY REVERSE MODELLING

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ABSTRACT

A series of numerical examples demonstrate that heterogeneities of the near-surface velocity structure affect the accuracy of the source position estimates using reverse-time modelling only, if their spatial extent is sufficiently large. Therefore, if small-scale inhomogeneities are present in the near-surface region, a homogeneous average velocity model for reverse-time modelling still leads to good source locations.

INTRODUCTION

Reverse modelling for source localization was shown to produce very accurate estimates of the source position even in complicated subsurface models, provided that the exact velocity model is known (e.g. Gajewski and Tessmer (2005)). In areas where reflection seismics has been done this assumption is true to a large degree. However, one might object that surface statics is not sufficiently known, which may result in a degradation of the accuracy of the estimates of the source position. Theoretical investigations (Müller et al. (1992)) predict decreased traveltimes in the presence of heterogeneities compared to a medium with the average velocity of the fluctuating medium. The relative amount of travel time change depends as well on the correlation length of the fluctuations compared to the seismic wavelength as on the standard deviation of the velocity fluctuations. To investigate the influence of velocity variations inside the surface layer numerical tests were performed.

NUMERICAL EXAMPLES

The model is made up of four layers. The seismic velocities from top to bottom are 2000, 2500, 3000, and 2000 m/s. The model is spatially discretized by a 10 m grid increment in both the vertical and horizontal direction. The time discretization Δt is 0.5 ms. The source time functions is a Ricker wavelet with a cutoff frequency of 80 Hz, i.e., the dominant frequency is 40 Hz. The dominant wavelength in the top layer therefore is 50 m. The source is located at $x = 360$ m and $z = 400$ m.

The forward modelling for the generation of synthetic seismograms is performed using the acoustic two-way wave equation, whereas reverse modelling for the localization is based on the acoustic one-way wave equation. For both, forward and reverse modelling, the Fourier method (Kosloff and Baysal (1982)) is used.

The different models for the forward modelling differ only in the surface layer. The thickness of the surface layer is 150 m, i.e., about 30 times of the prevailing wavelength. For the examples different correlation lengths l_{corr} were chosen: 2.5 m, 5 m, 10 m, 25 m, and 50 m. The scattering layer is constructed by a convolution of an Gaussian function by normal-distributed random numbers (e.g., Frankel and Clayton (1986)), where the standard deviation is 5%. This leads to extreme velocities of $\pm 20\%$ around the mean velocity. For comparison the first model has a homogeneous top layer. Contrary to the forward modelling the reverse modelling is done using the mean velocity in the top layer. The figures show the subsurface model and the respective seismograms recorded at the surface. Bright and dark colours in the subsurface models denote low and high velocities, respectively. The comparison of the different examples show that the arrival times of the direct wave fluctuate more strongly with increasing correlation length. The source positions for the numerical examples with different surface layers which were estimated by the reverse modelling method are given in the table. The result in the last row ($l_{corr} = 50^*$) was achieved using the same random velocity model for forward and reverse modelling. In this case the source position was estimated exactly.

l_{corr} [m]	estimated source location [m]
2.5	(360,400)
5	(360,400)
10	(350,410)
25	(340,420)
50	(340,400)
50*	(360,400)

In further tests in addition to surface statics random noise was added to the seismograms. This was applied to the model with a correlation length of 50 m. The signal to noise ratio was 0.5, which means quite strong noise. A certain realization is shown in Fig. 13. Here the localization method found (340 m, 420 m) as the source position, which differs from the position found without noise. Tests with many realizations show a weak dependency on the random noise realization. The majority of the localizations yielded (330 m, 440 m) for the source position. A snapshot of the wave field at maximum focusing of the noisy recordings is shown in Figure 14.

CONCLUSIONS

From the numerical tests it is found that a scattering surface layer has little influence on the localization accuracy of the reverse modelling method if there are rapid spatial fluctuations of the seismic velocities. This is an intuitively exspected result, since small sized inhomogeneities simply cannot be 'seen' by the seismic waves and the velocity variations are averaged out. However, if the correlation length of the velocity fluctuations is of the order of the dominant wavelength or larger the seismic wave 'sees' such inhomogeneities and the waves travel partially faster or slower with respect to the background velocity.

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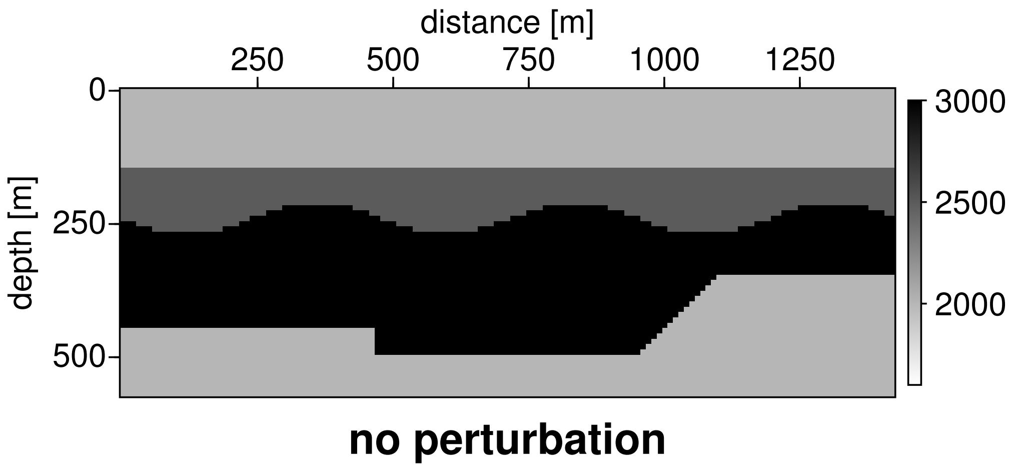

Figure 1: Model without scattering surface layer

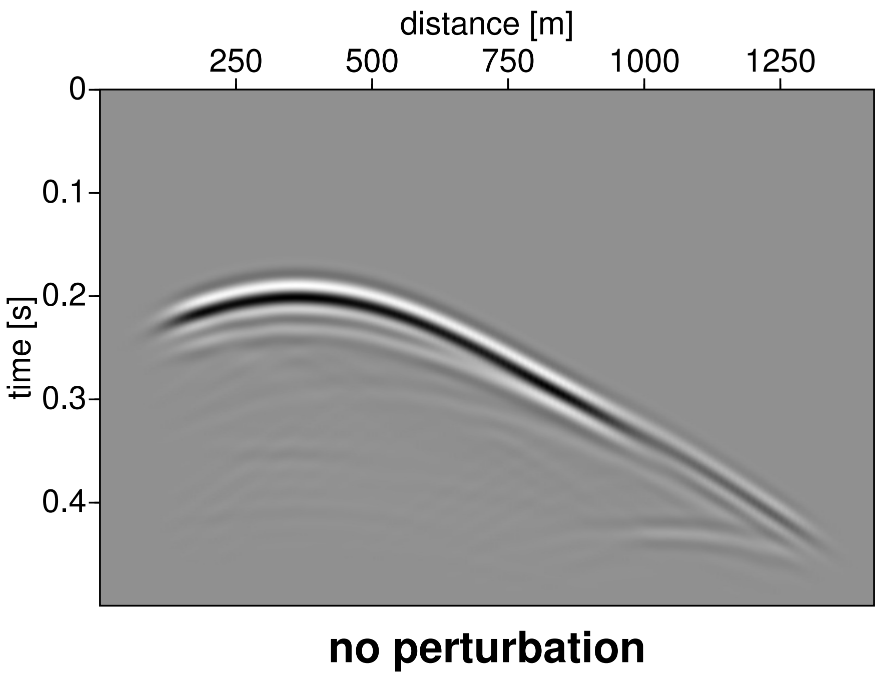

Figure 2: Seismogram section from model in Fig. 1

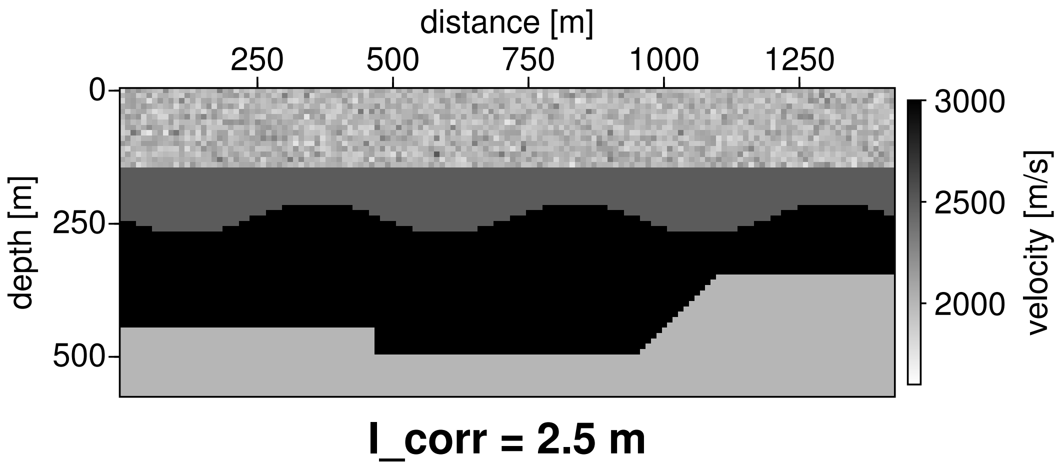

Figure 3: Model with a correlation length of 2.5 m in the surface layer

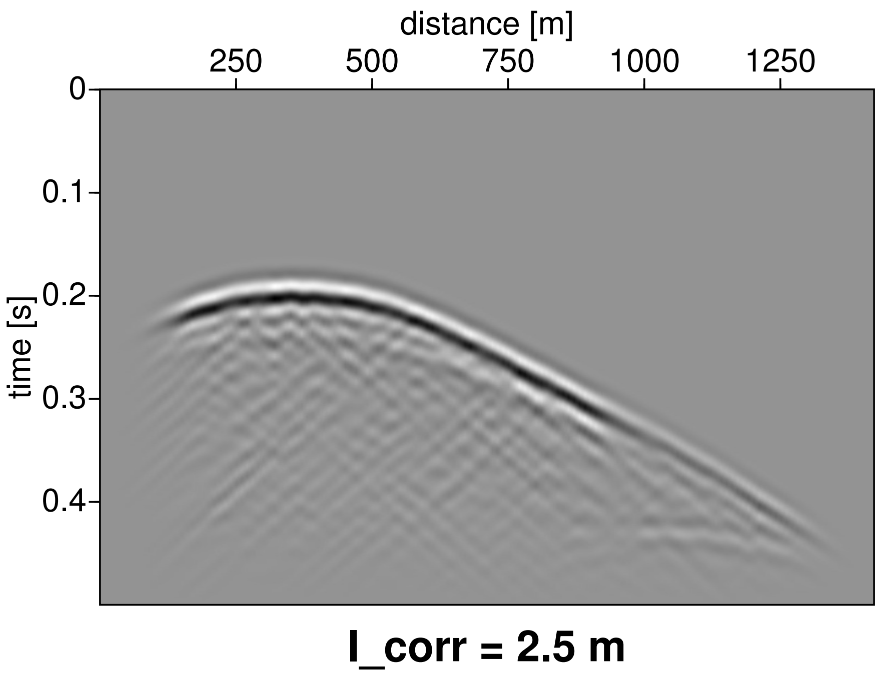

Figure 4: Seismogram section from model in Fig. 3

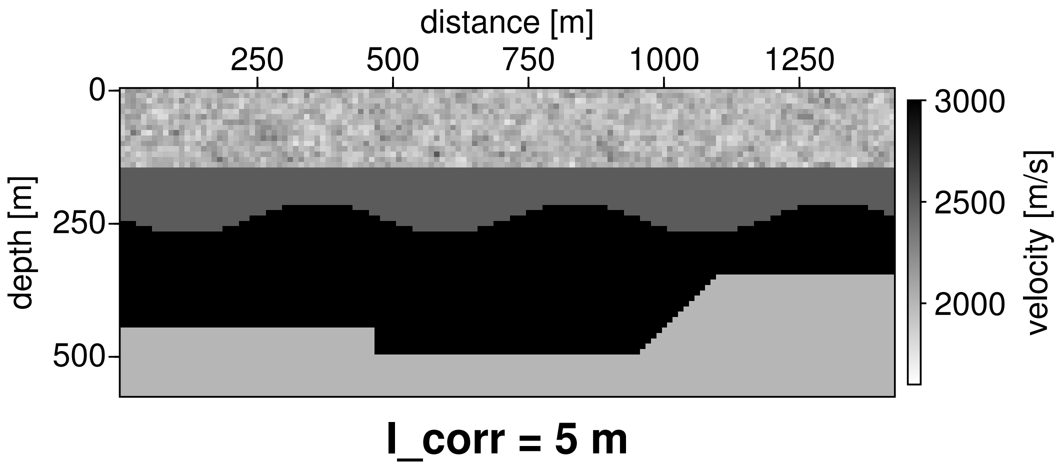

Figure 5: Model with a correlation length of 5 m in the surface layer

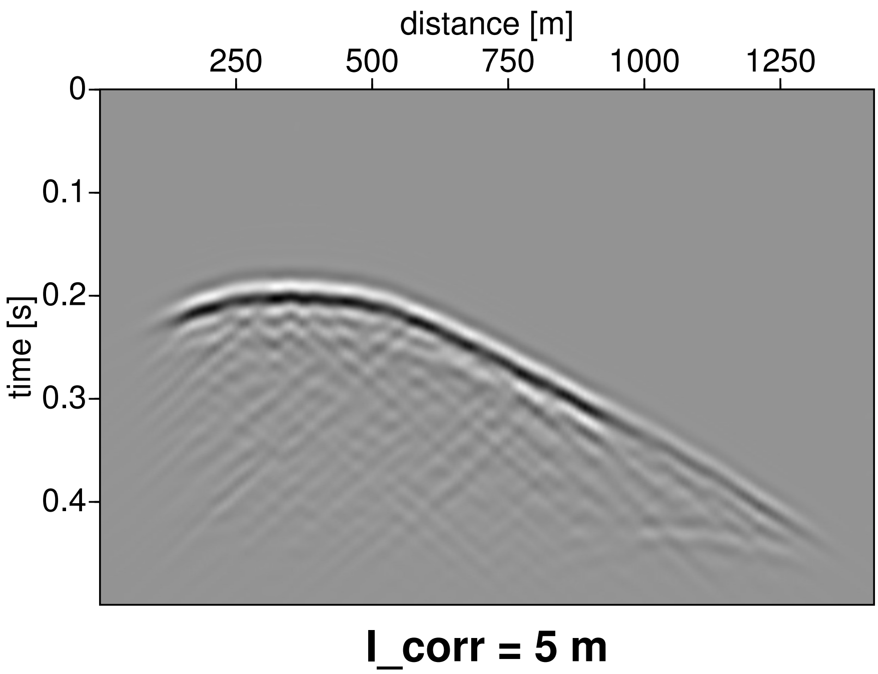

Figure 6: Seismogram section from model in Fig. 5

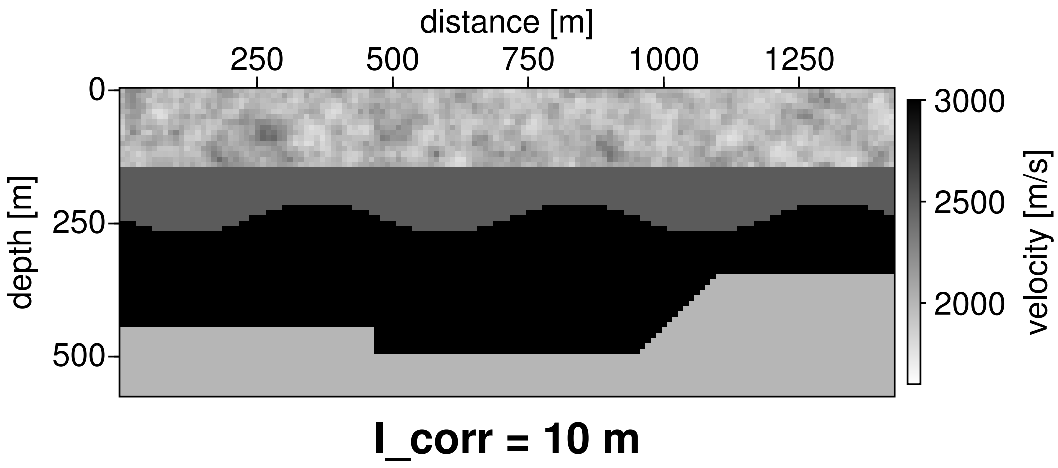

Figure 7: Model with a correlation length of 10 m in the surface layer

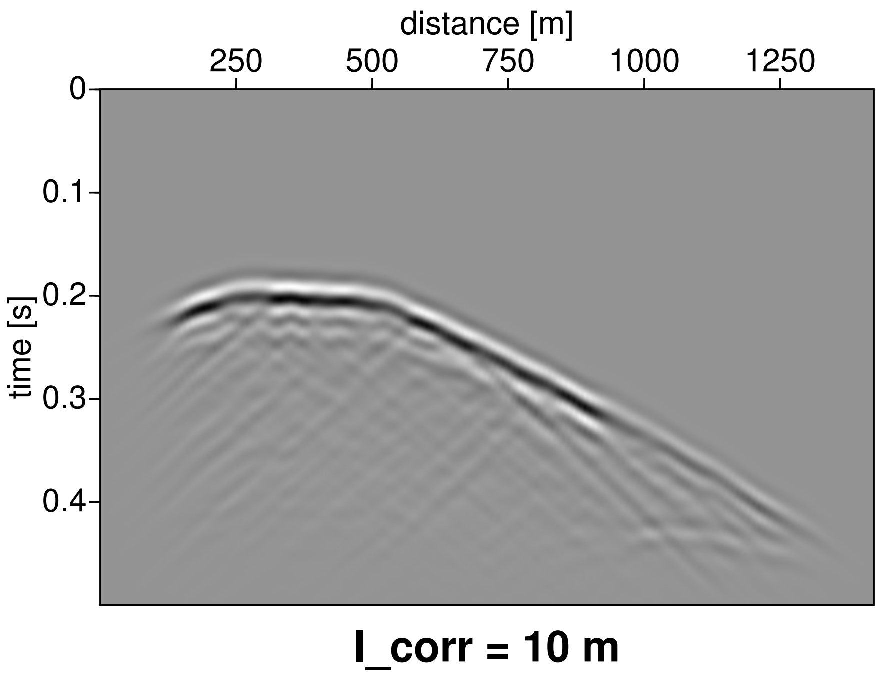

Figure 8: Seismogram section from model in Fig. 7

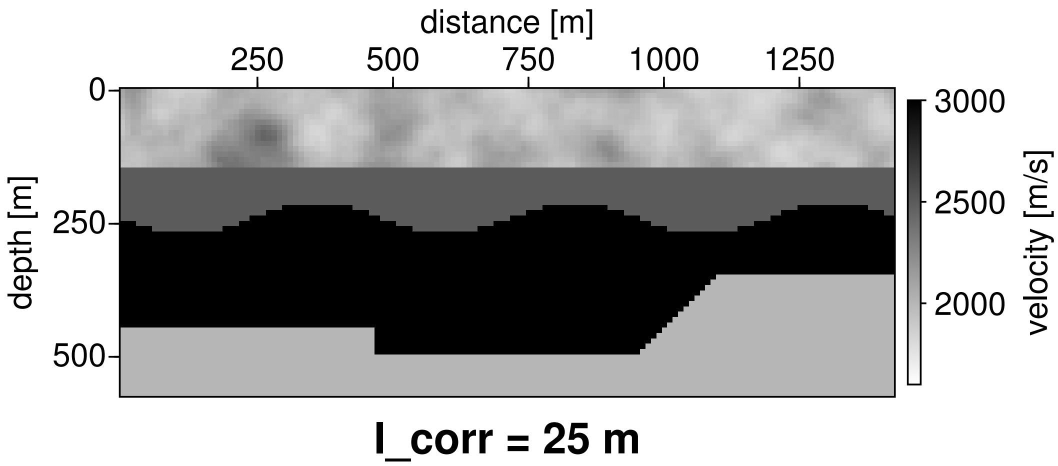

Figure 9: Model with a correlation length of 25 m in the surface layer

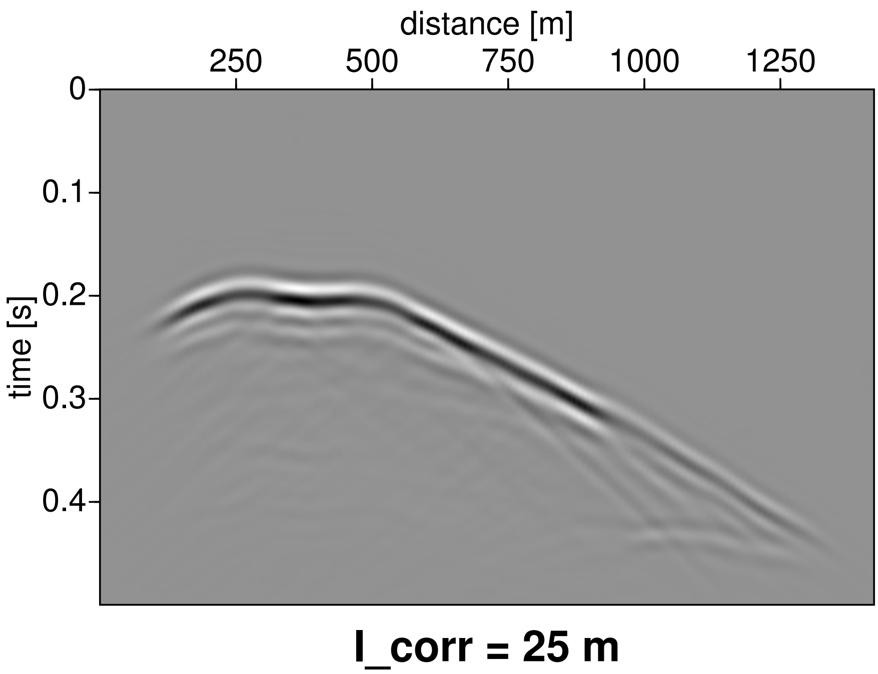

Figure 10: Seismogram section from model in Fig. 9

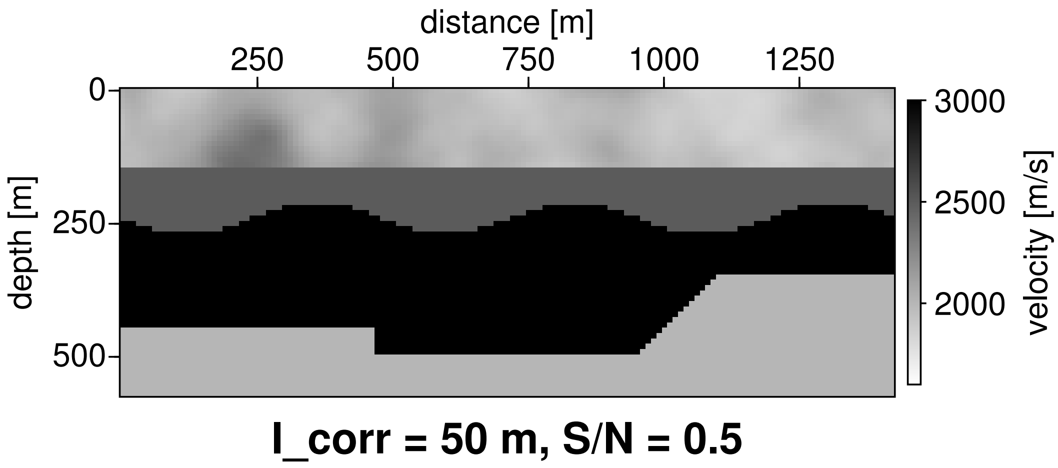

Figure 11: Model with a correlation length of 50 m in the surface layer

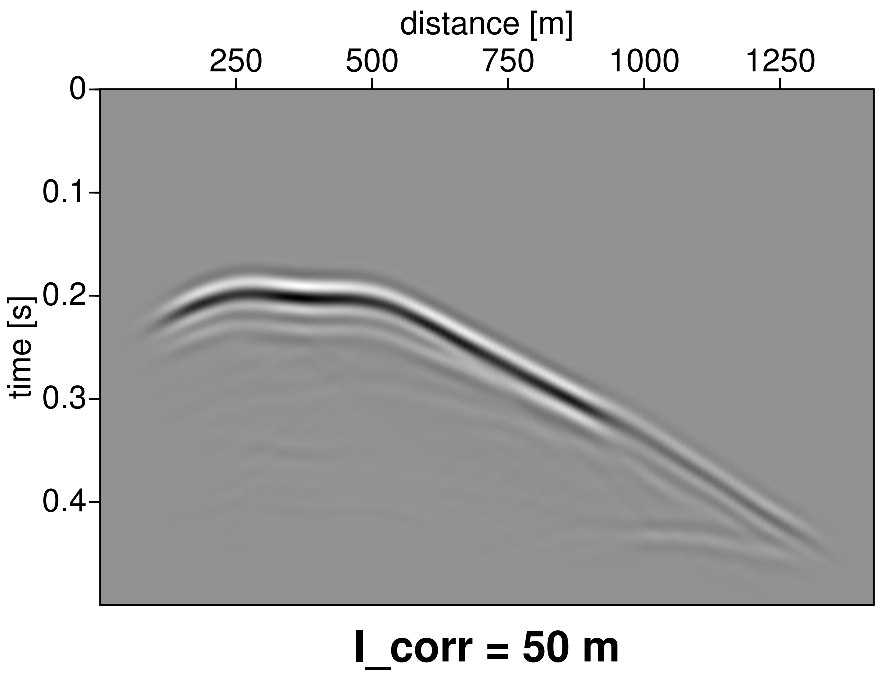

Figure 12: Seismogram section from model in Fig. 11

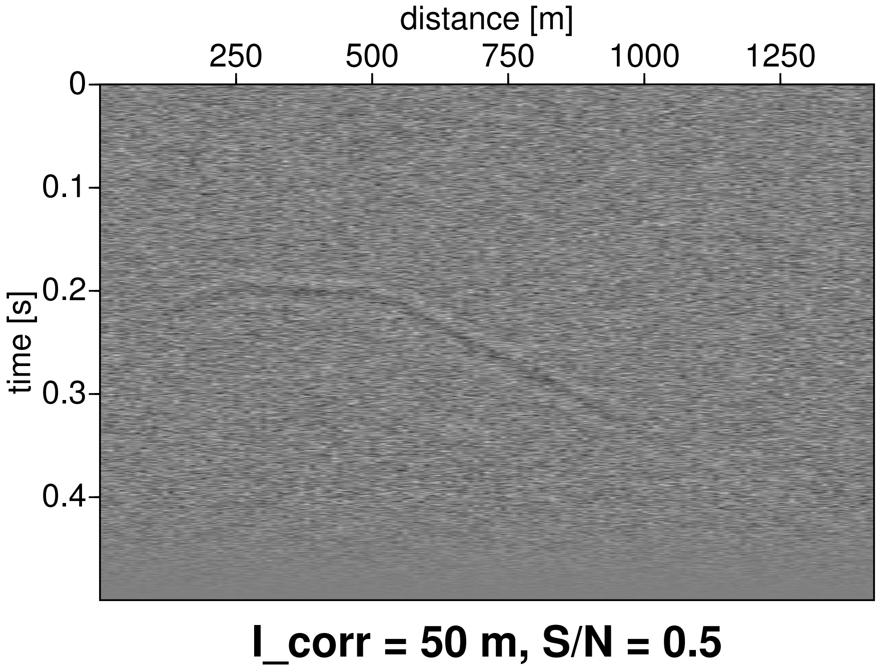

Figure 13: Seismogram section from model in Fig. 11 with noise added. Signal to noise ration is 0.5

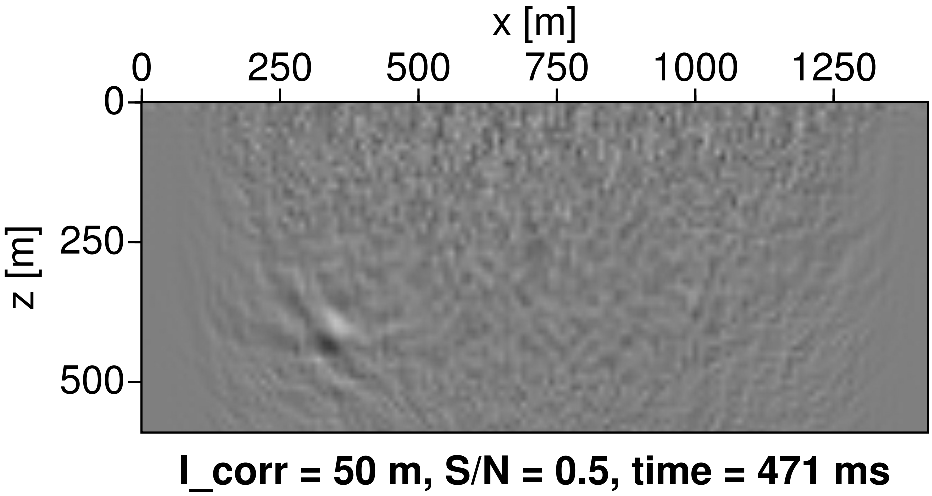

Figure 14: Snapshot at source time estimated from reverse modelling of seismogram recordings in Fig. 13.