Application of acoustic waveform tomography to marine seismic reflection data contaminated with strong guided waves

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Abstract

Two-dimensional frequency domain acoustic waveform tomography is applied to a small marine seismic reflection section contaminated with strong guided waves which are highly dispersive in nature. We show that, it was possible to obtain a reasonable P-wave velocity model by careful preconditioning of the data. We describe the problem in terms of the average amplitude variation of the first arriving wavetrain of these data with offset bins (AVO), and present a strategy to recover a subsurface velocity model that reproduces the observed field data.

Introduction

In this study, a small seismic reflection section, which consists of 201 shot gathers, was used from offshore southwestern Alaska. At this location, the water bottom is shallow, i.e. less than 100 m, and due to the nature of the shallow seafloor region the seismic data are contaminated with high amplitude laterally travelling guided waves. The seismic section was acquired with a maximum offset of 4230m and near offset of 255m. The shot interval is approximately 50m and receiver interval is 25m. A raw shot gather with minimum phase low-pass filter (0-0-15-20Hz) from the section is shown in Figure1. First arrivals are partly obscured by the strong dispersive guided waves, as indicated by the red arrows in the Figure 1.This high amplitude linear coherent noise is present on almost all the shot gathers.

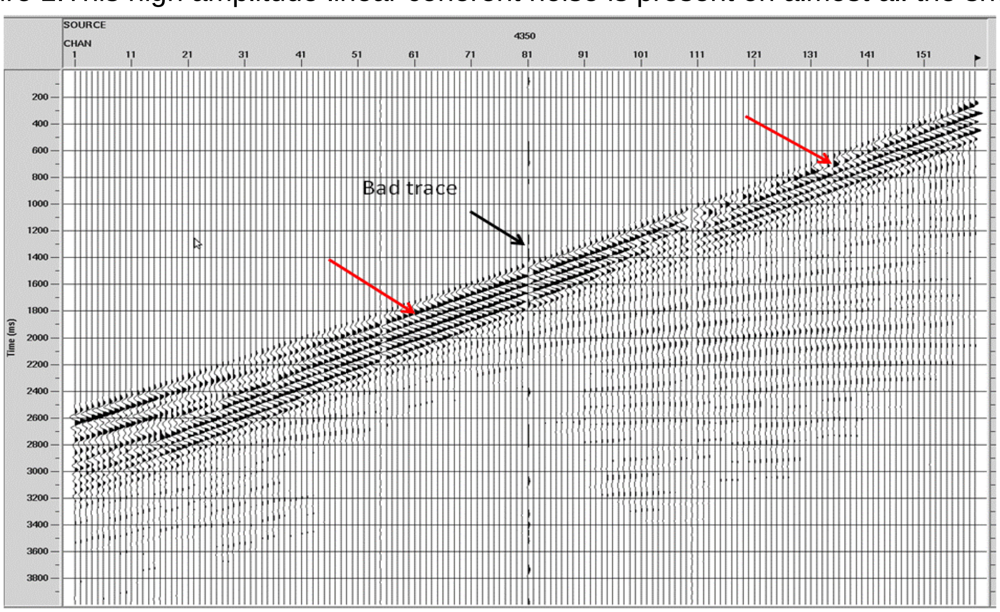


Figure 1: Raw shot gather minimum phase low pass filtered with corner frequencies 0-0-15-20Hz

Frequency-Wavenumber (F-K) domain filtering is of little much use, because these guided waves have a similar apparent velocity to the first arrivals. Since these guided waves are elastically coupled, they cannot be modeled in acoustic waveform tomography.

Starting velocity model and source signature estimation

We used first arrival tomography code of Aldridge and Oldenburg (1993), which is based on a finite difference solution of the eikonal equation to derive a starting velocity model for waveform tomography from picked first arrivals. The starting velocity model satisfies a common convergence criterion, i.e. it is able to predict the first arrival to within half a cycle (Sirgue 2003). This requirement was tested by carrying forward modeling with the starting velocity model, and then comparing the travel times of the synthetic and field data. The source estimate needed for the first inversion was derived by using this starting velocity model from an initial assumed wavelet comprising a simple spike, as shown in Figure 2. The consistency of the source estimate from shot to shot provides an indication of the good quality of the starting model.

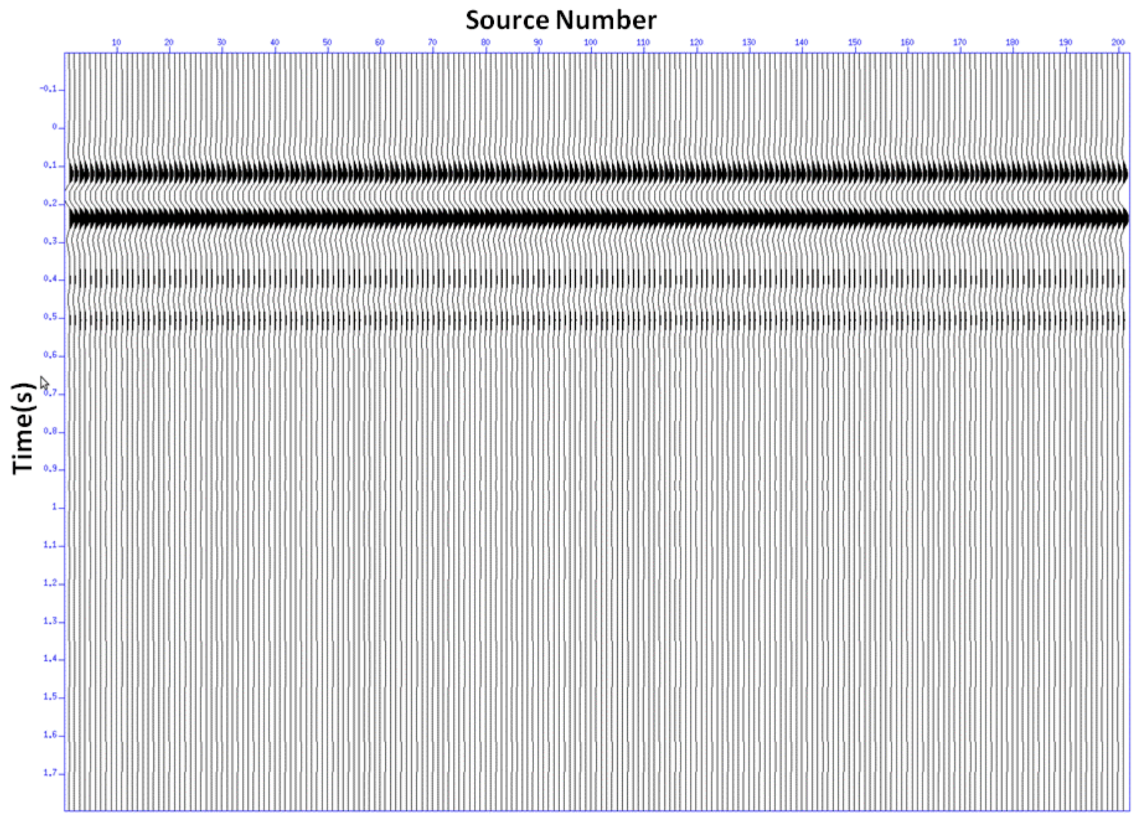


Figure 2: Individual source signatures extracted from starting velocity model

Data preconditioning

Preconditioning of data is required to ensure the data input to waveform tomography are as consistent as possible with the (acoustic) assumptions of the method. This implies that any aspect of the data that is not predicted by the 2D acoustic propagation scheme, e.g. shear waves, coherent noise, shot to shot energy variations, amplitude discrepancy, and bad traces should be removed or corrected (Takam Takougang and Calvert, 2011). For the present study, we first resampled the data to 4ms and killed some of the bad traces shown in Figure1. Since method assumes 2D wave propagation, the 3D seismic data are corrected for geometrical spreading, i.e. the data were multiplied by t^0.5. Shot gathers were then subjected to amplitude balancing to avoid any shot to shot variations which can bias the model update during the inversion. The data were then low pass filtered with minimum phase using corner frequencies (0-0-15-20Hz) of an Ormsby filter with 0.25% prewhitening. Time windowing is applied to the shot gathers to exclude late arrivals, multiples and include first arrivals, direct and refracted energy and early secondary arrivals. The seismic data were finally arranged in reduced time with a reduction velocity of 2000m/s to ensure the inclusion of all arrivals during inversion, and reduce the computational cost.

Amplitude Scaling

A scaling factor should be applied to the amplitudes of processed field data as described by Brenders and Pratt (2007) to minimize effects arising from complex geometrical spreading, 3D scattering effects etc. Because the above method assumes a straight line approximation of the average RMS amplitude variation of the dataset with offset bin to calculate the correction factor, we need to ensure this AVO behavior of the modeled and field data is similar. So a single comparison was made between RMS amplitude variation with offset bins of the processed field gathers with the modeled data, derived after forward modeling using the velocity model from travel-time tomography are shown in (Figure 3a and 3b).The amplitude versus offset behavior which is often critical for the successful inversion is clearly dissimilar for these two datasets. This disparity is mainly due to dispersive nature of guided waves that affected the amplitudes of the arrivals mainly at middle offsets as shown by black arrow in Figure 3a.

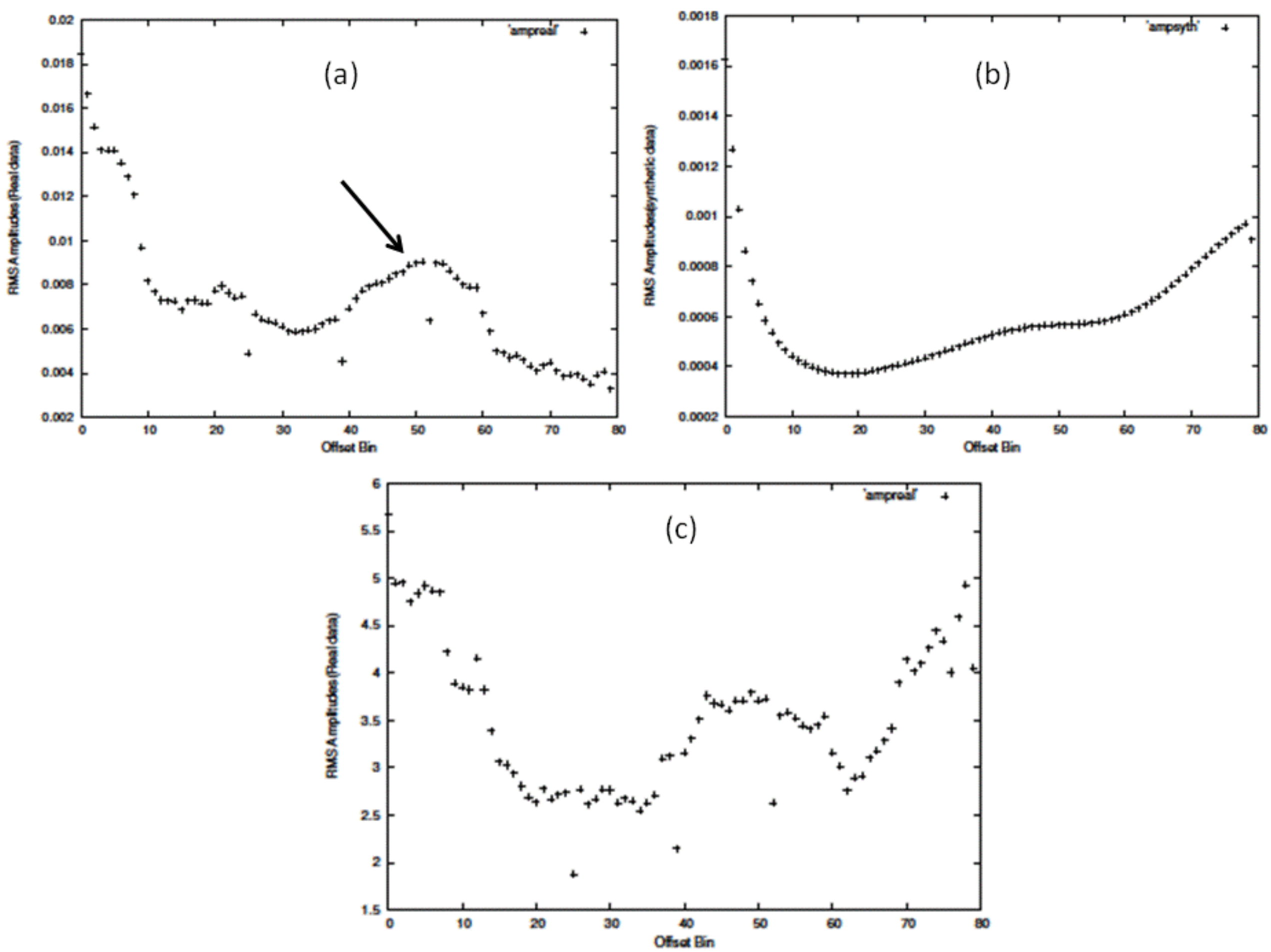


Figure 3: RMS Amplitude variation with offset bins (offsets are binned every 50m) of (a) the field data after minimum phase low pass filtering 0-0-15-20Hz, 2D converted, Shot-to-shot amplitude balancing (b) the amplitude variation of the forward modeled data using the starting travel time model (c) the new processed data after minimum phase low pass filtering 0-0-11-13 Hz

To mitigate this problem, a sharp minimum phase low-pass filter 0-0-11-13Hz was applied to the field data to remove much of the guided wave energy, which was present at higher frequencies. The RMS amplitude variation with binned offsets of this filtered, processed data is plotted in Figure 3c. We now observe that the AVO behavior of the new processed data (Figure 3c) and modeled data (Figure 3b) looks similar. We then calculated the correction factor and applied amplitude scaling to these new processed field data. The final processed data ready for inversion and its associated amplitude spectrum is shown in Figure 4a and 4b. Because of the sharp low pass filtering, some low frequency noise is introduced in to the final processed data as shown in Figure4a.

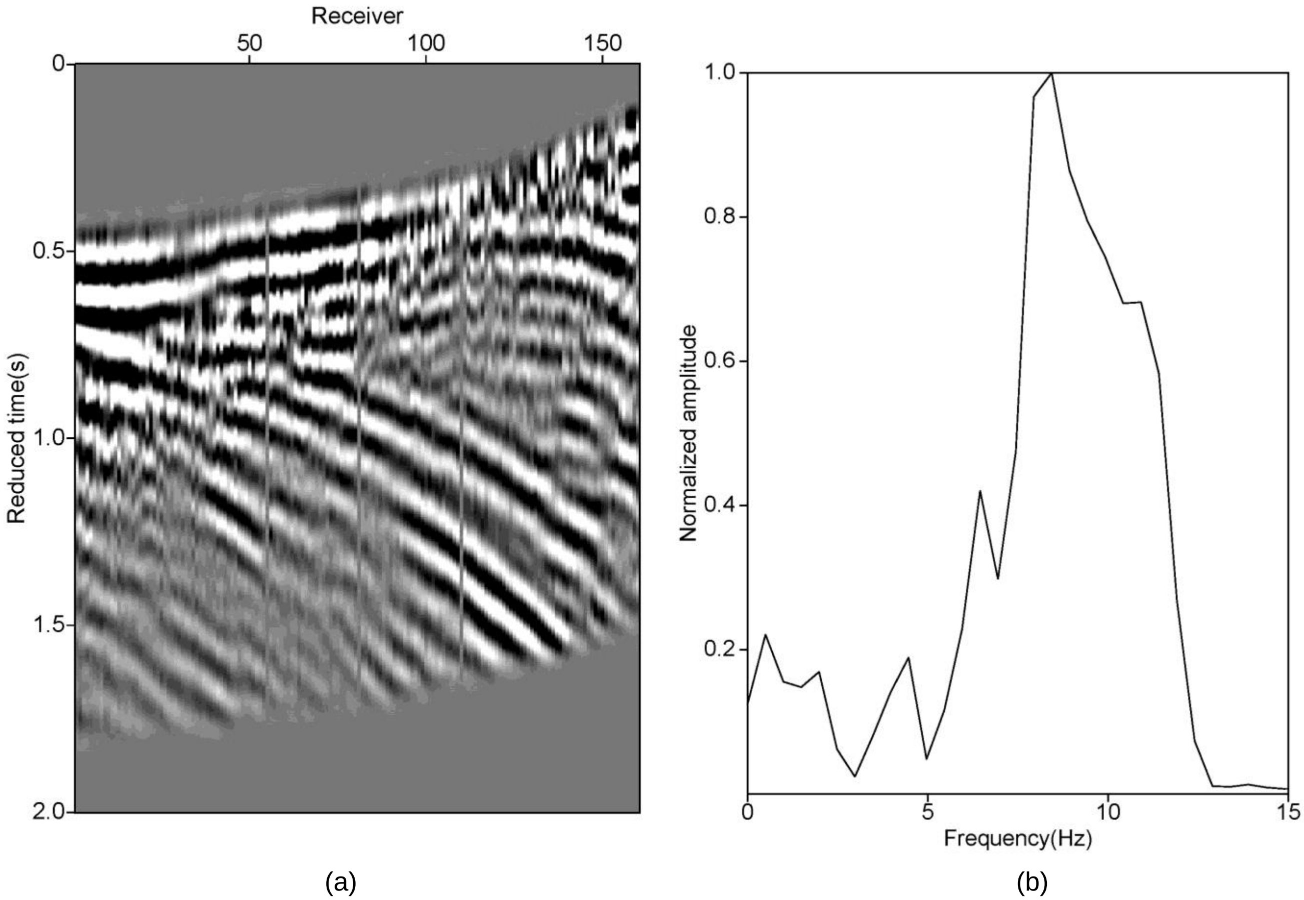


Figure 4: (a) Final processed data ready for waveform inversion. The data contains frequencies 5-12 Hz displayed using a reduction velocity of v=2000 ms^{-1} (b) Associated amplitude spectrum

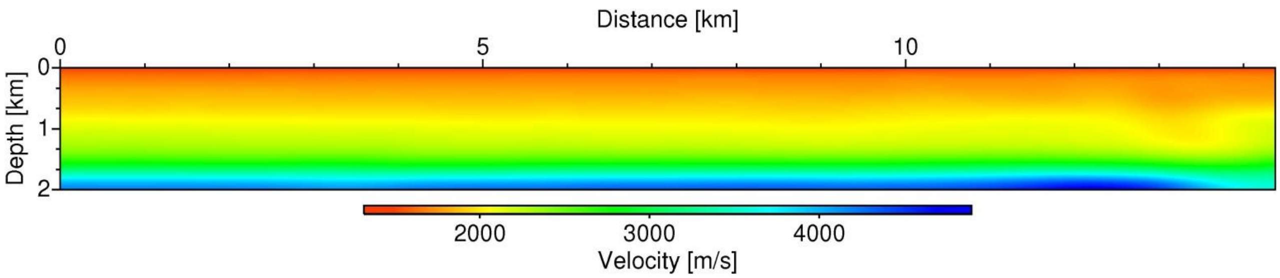
Inversion

Waveform inversion is carried out using a gradient descent method. Low frequencies and a good starting model, which provides long wavelength variations in the velocity model, are necessary for successful waveform inversion. The sampling interval in the frequency domain was chosen based on time window we have selected for field data. In the present case the time window is 2s and therefore corresponding frequency interval is 0.5 Hz. As the starting frequency of the data used in the inversion is relatively low (5Hz), and the starting velocity model Figure 5a satisfied convergence criterion, we can mitigate to some extent the convergence problems due to nonlinearity.

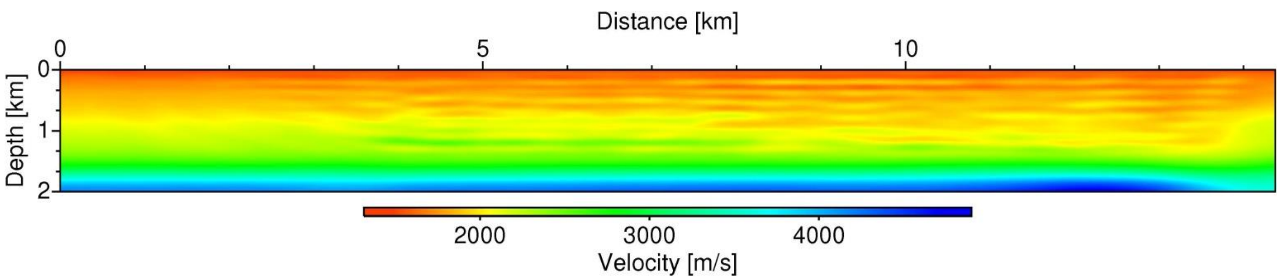
For frequency domain modeling, a time damping term τ= 0.8s which correspond to an aperture of 40% of the 2s input data window was applied to suppress time wraparound problems caused by late arrivals. The source estimate needed for the first inversion was derived from the initial velocity model derived by ray based tomography and an spike initial wavelet. In each succeeding step of the inversion the source is updated by using the scaling function (Pratt, 1999).Normally all frequencies are not inverted simultaneously due to the large computational cost. In the present case, we used groups of three frequencies {(5, 5.5, 6), (6.5, 7, 7.5), (8, 8.5, 9), (9.5, 10, 10.5), which were inverted for both amplitude and phase simultaneously. At first, lower frequencies are inverted and higher frequencies are sequentially inverted. Figure 5a show the initial velocity model derived from travel tomography. Figures 5b and 5c show the inversion results after the first (4.5, 5, 5.5) and last (9.5, 10, 10.5) steps of waveform tomography.

Results and Conclusions

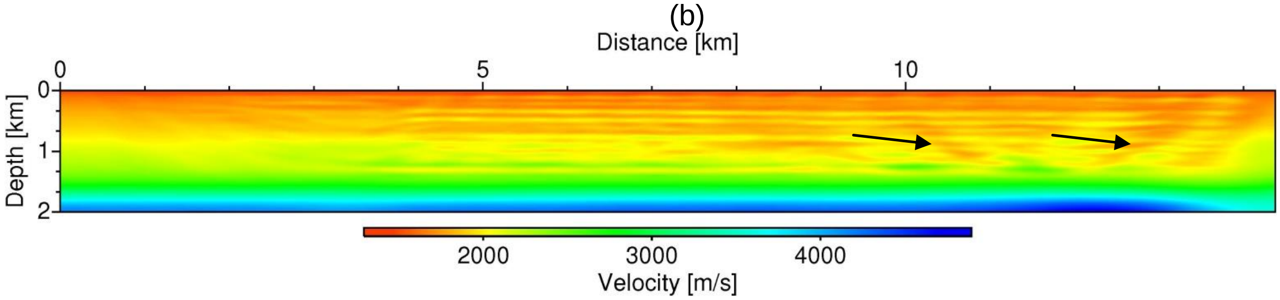
We can clearly identify the layering in the sediments and an increase of resolution as the frequency increases. But as we invert for higher frequencies, some velocity anomalies believed to be artifacts are enhanced as shown in Figure 5c by arrows. We can also notice lateral variation of the velocities along the profile.



(a)



(b)



(c)

Figure.5: (a) Starting velocity model derived from Travel time tomography (b) after (5, 5.5, 6) Hz inversion (c) after (9.5, 10, 10.5) inversion,

Acknowledgements

We are grateful to Gerhard Pratt, who provided us with his waveform tomography code.

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