Multiparameter inverse scattering: computational approaches

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Abstract

Inverse scattering is a key theoretical and practical tool in seismic imaging and inversion. With specific computational approaches it is possible to ascertain the material properties of the subsurface using scattered acoustic waves. We seek to determine multiple rock parameters such as density and bulk modulus from reflected seismic signals. At this early stage of investigation a basic approach is used based on straightforward inverse scattering equations. In this case we will examine how multiparameter inverse scattering in a constant 2D background works and what are the results of inverting synthetically generated data.

Synthetic Examples

For these experiments we have fixed the model parameters at a x line length of 2500m and a depth of 1000m (t=0.8 sec), we then choose a source/receiver spacing of 10m and a sampling time of 4ms. For the forward differencing calculations the time step is 0.5ms between frames and a computation grid of 10m in the x direction and 5m in the z direction.

A bandlimited source wavelet was also added which in this case is a Ricker wavelet at 30Hz and 0.1 seconds.
In each case the initial velocity map was used as input into the CREWES forward differencing routines displayed, followed by a snapshot at one particular source point comprising the gather of the receivers for that source point.

A deconvolution was then done on all the shot profiles and a single one is displayed, usually at the same source point, x=1195m, the displayed image has the direct wave subtracted prior to the deconvolution. We also display the kz-km space to illustrate the frequency coverage of the model.
The shotpoint images were scaled using mean value and not max value scaling to bring out the details of each of the models and results. Finally we display result of the inversion process.

Conclusion

Even with the relatively straightforward algorithm for a constant background, we are able to image the models to a fairly high degree of accuracy. Our simulations have not taken into account real world effects such as multiples and anisotropic and anelastic media which are variable background effects.

We need to verify that the amplitudes of the reflections found in these results are true amplitudes. Also material parameters such as bulk modulus, variable density need to be built into the models to test the accuracy of the inversions in producing the correct, physically realistic answers.

Much more remains to be done in regards to further numerical investigations of multiparameter inverse scattering and the inversion algorithms predicted by this approach.

References
Clayton, A.W. and Stolt, R.H, 1981, A Born-WKBJ inversion method for acoustic reflection data, Geophysics, 46, 1559-1567.

Acknowledgements
This investigation started out as a summer student project, funded through grants to Prof. Kris Innanen.I wish to thank him for the advice and guidance as well as the initial code as a template to develop this simulation.

Four layer horizontal model

This physically simple model demonstrates the power and accuracy of the inversion routine, in Figure 2 and Figure 3 we get the expected responses from the forward differencing model. Hyperbolic features corresponding to the model reflectors and in the deconvolved case as in all cases we've subtracted the direct wave. We do get some high frequency "wakes" following each of the hyperbolic returns plus reflections from the sides of the aperture.

In Figure 4 we can see a very simple one dimensional column, this is because there is only the horizontal reflectors which are flat and so no variance in relative angle. Figure 5 shows the resulting inversion, we have some wakes and aperture artifacts on the sides. But we do get the expected number of layers with reflector 1 at the model depth expected. The difference is in the depth of the 2nd and subsequent layers. Reflector 2 and 3 are shallower than the actual reflectors, but they are not shallower than expected. This is an expected result, and correction requires either a more accurate background model or higher order inverse scattering terms be added.

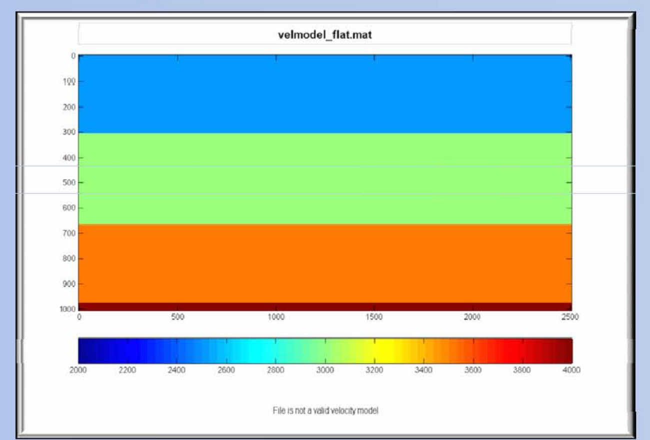
Figure 1: Four Layer Horizontal Velocity Model

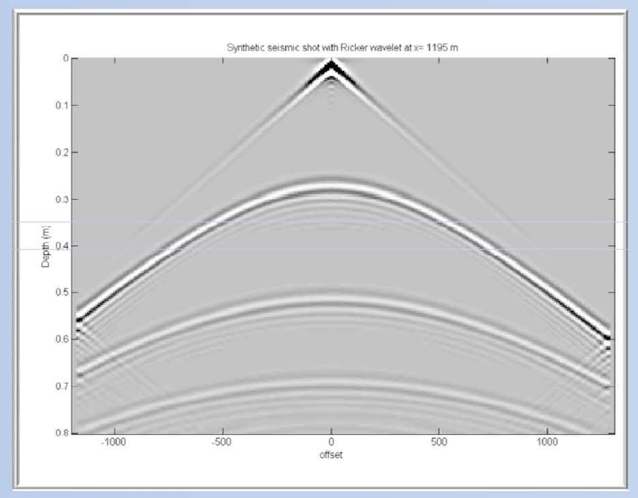
Figure 2: Four Layer Shot Profile w Ricker wavelet

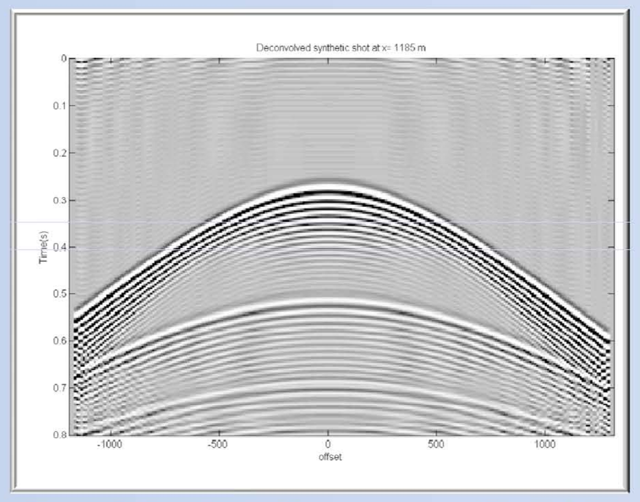
Figure 3: Four Layer, Deconvolved w/o Direct Wave

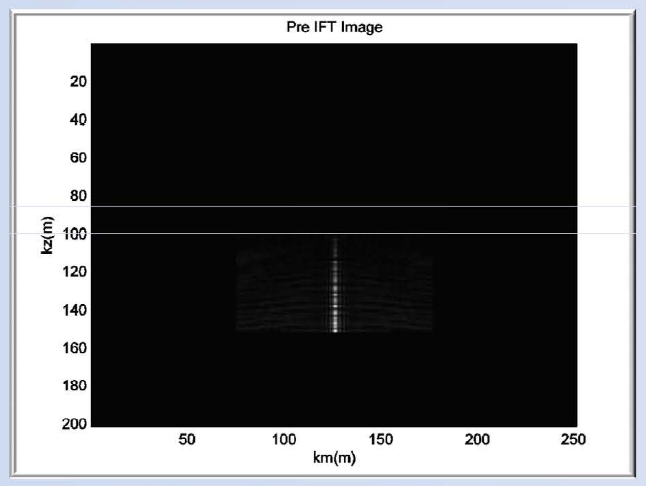
Figure 4: Four Layer, Kz-Km Plot

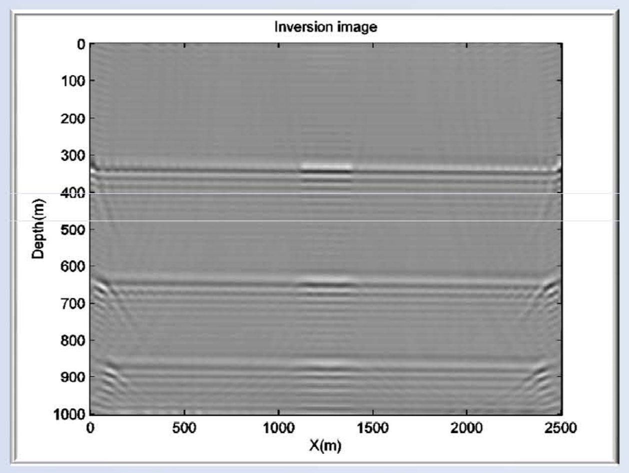
Figure 5: Four Layer Horizontal, Inversion Image

The Shallow low velocity model

The shallow, low velocity model was created to see if the inversion properly placed the deep reflectors when encountering a low velocity layer. In this case we have a biconvex lens As can be seen from Figures 7 and 8 there is a lot of detail in the lower parts of the shot profile. This is complicated by the high frequency wakes generated by the structures so it's very difficult to tell what is a true reflector and what is noise.

In Figure 9 we can see how the signal is distributed in k-space, there is a broad area of signal in a cone with some possible aliasing. Finally in Figure 10 the inversion image looks fairly realistic, compared to the velocity model the upper and lower reflectors have the correct shape and form. Again the lower convex part of the intrusion is not located in exactly the correct depths due to the velocity difference not being put into the reference medium, but different velocities are accommodated by the theory.

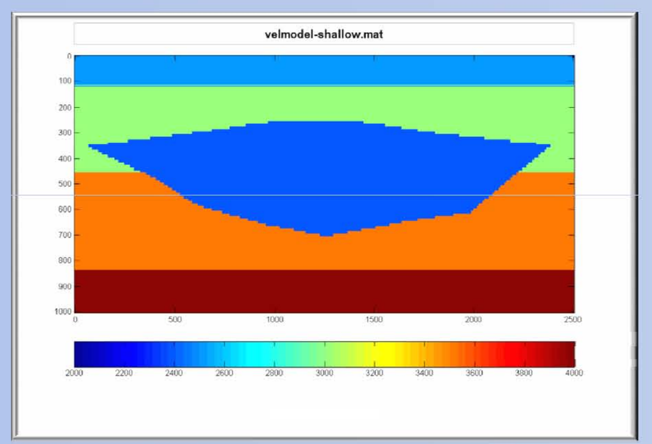
Figure 6: Shallow Lens Velocity Model

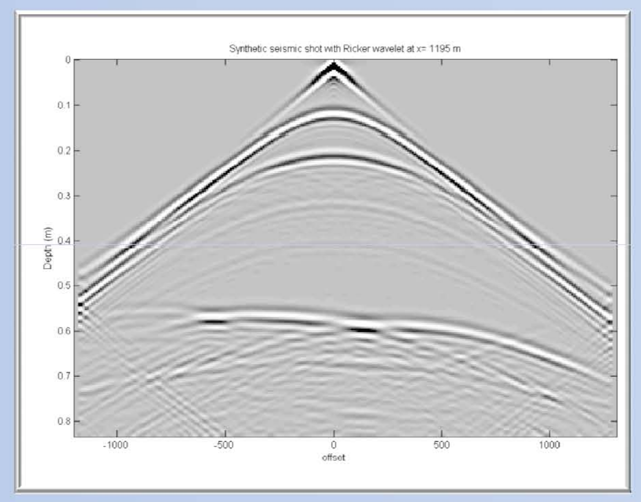
Figure 7: Shallow Lens Shot Profile w Ricker wavelet

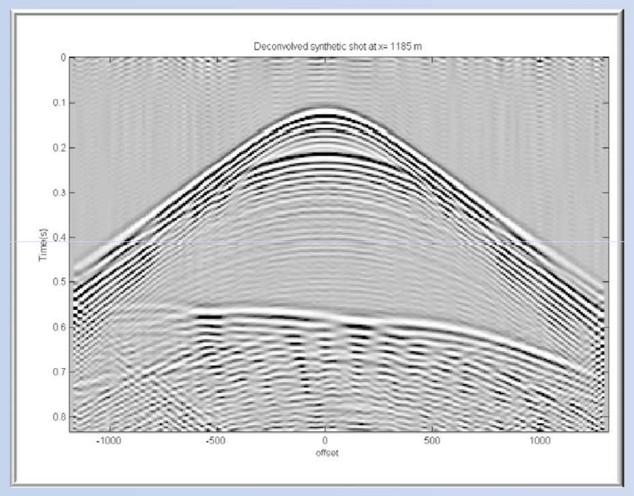
Figure 8: Shallow Lens, Deconvolved w/o Direct Wave

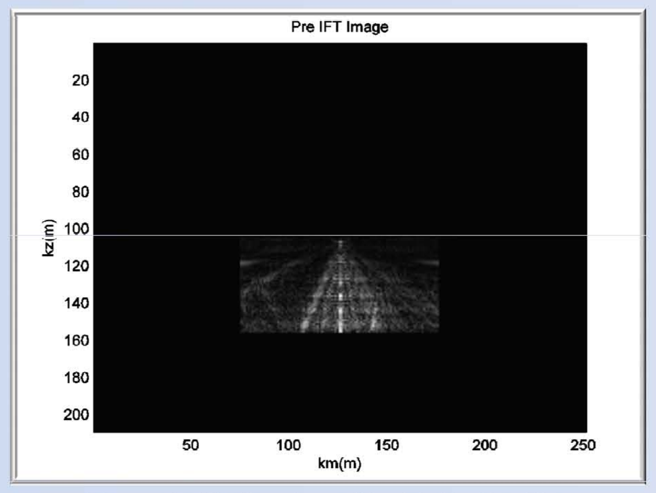
Figure 9: Shallow Lens Model, Kz-Km Plot

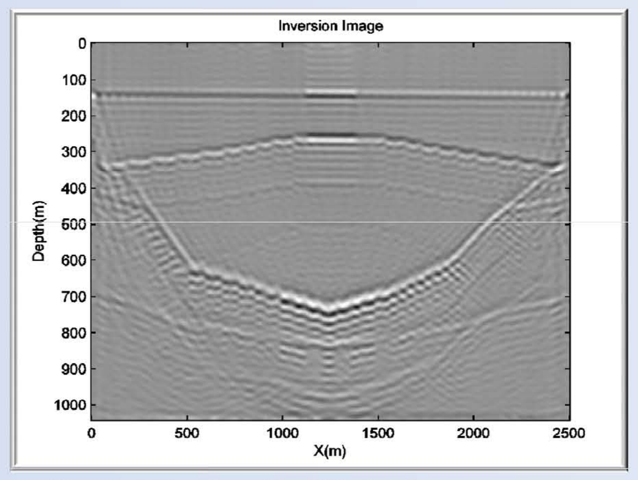
Figure 10:Shallow Lens Model, Inversion Image

The Anticline velocity model

The Anticline velocity model shown in Figure 11 also has a low velocity center but has a concave upper surface and a convex lower surface which should create significant distortion. The sides of the upper surface have a greater slope towards the ends while the lower surface has a fairly consistent and shallow angle.

Unlike the shallow biconvex lens model the anticline model seems to have less noise and a cleaner profile as seen in Figures 11, the Ricker convolved data and the deconvolved shotgather in Figure 12, Figure 13 seems to have a cleaner look as well with less apparent spread in the signal.
Of course the inversion image in Figure 15 shows that the structure was reproduced fairly accurately, the steeper side of the upper surface seem to drop in amplitude as a result of the large angles with respect to the placement of the source and only shows up weakly in the plot.

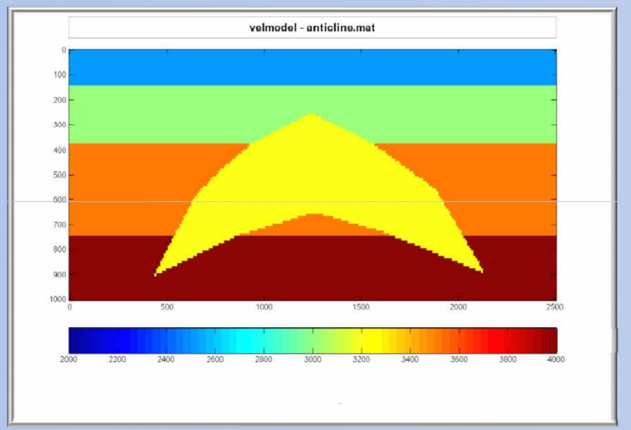
Figure 11: Anticline Velocity Model

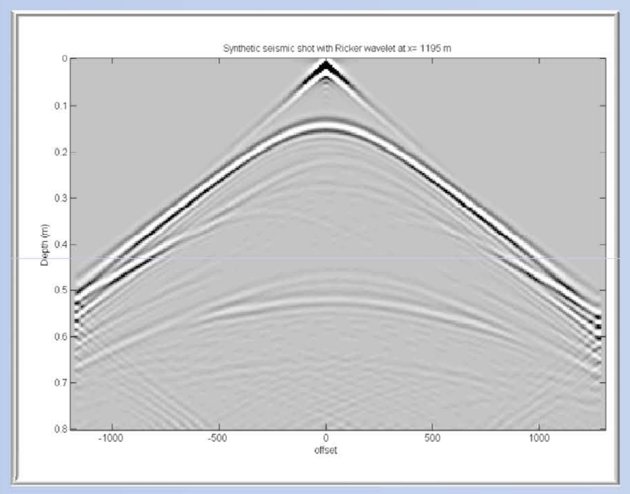
Figure 12: Anticline Shot Profile w Ricker wavelet

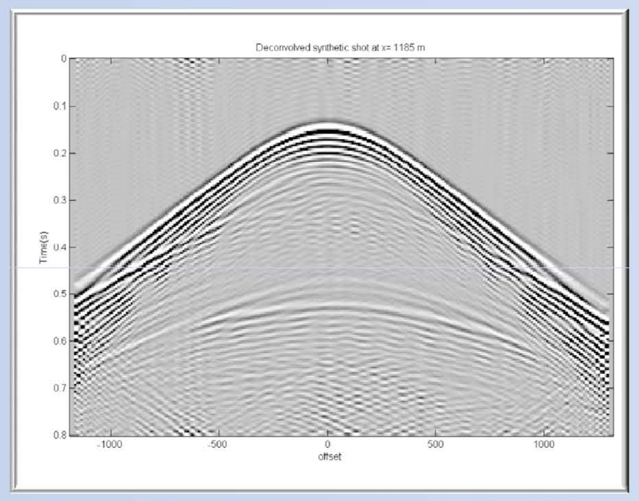
Figure 13: Anticline Deconvolved w/o Direct Wave

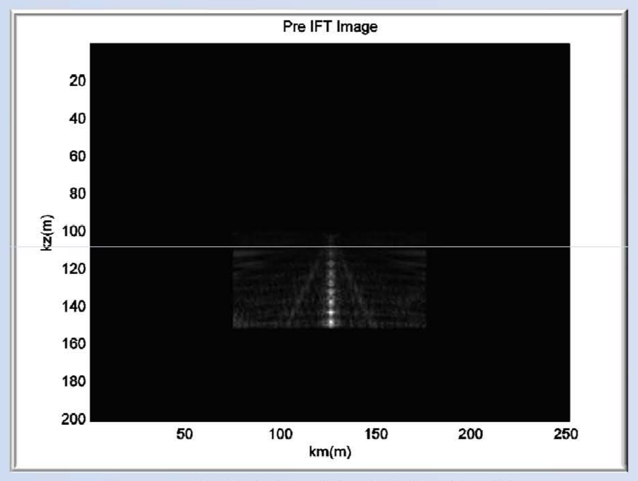
Figure 14: Anticline Model, Kz-Km Plot

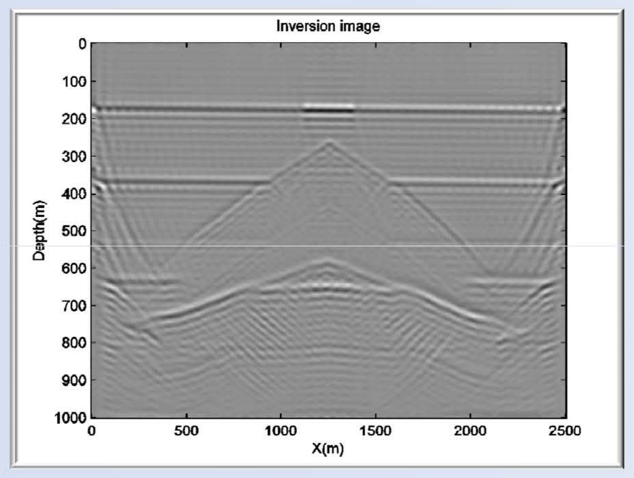
Figure 15: Anticline Model, Inversion Image