Numerical experiments of Full Waveform Inversion on a typical Pre-Salt Model. Part 1: stability in relation to initial velocity field

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Abstract

In this paper, we apply our Full Waveform Inversion scheme to investigate its stability in relation to the initial velocity model. We use a typical pre-salt model based on Santos Basin, offshore Brazil. For a fixed spread acquisition pattern, we generate an acoustic synthetic dataset using our finite difference code. We start from three velocity models: a) a smoothed version of the true one, b) a velocity model obtained by extrapolating the information observed along a pseudo well and, c) a homogeneous velocity model. For low frequencies (the lowest one equals to 3.5 Hz) and long offsets (about 5 times the depth of the targets), in the first two cases, except for some small artifacts, we succeed in recovering the desired model as a whole. For the homogeneous initial velocity, we were able to get a reasonable approximation down to the top of the salt layer.

Introduction

Full waveform inversion (Lailly, 1983 and Tarantola, 1984) has the perspective of being one of the most useful tools in the seismic processing workflow. In fact, the improvements of the velocity field provided by this method may increase the quality of depth migrated seismic data, significantly. Moreover, the velocity field itself may become an interpretation tool as well (see Valhall case in Etienne et al. 2012).

On the other hand, on some offshore Brazilian basins, we are facing the problem of describing and monitoring the production of complex reservoirs located just bellow very thick salt layers (Mohriak et al. 2008).

Seismic imaging enhancement may strongly impact the characterization and management of oil and gas field in those areas. Our aim is to put in evidence the improvement that the FWI may bring for the velocity model building under these complex scenarios.

In this context, we tackle the question of stability of the method in relation to the starting velocity model through 2D numerical experiments. As long as a good quality seismic dataset is available (presence of low frequencies and long offsets), the FWI may provide the main features of the desired model even if a rough initial velocity model is used.

Method

The FWI may be formulated as the problem of minimizing with the respect to the geophysical parameter, m (in this work, the square of the p-slowness), the L_2-norm misfit functional of the observed data, d, and the modeled data, $u(m)$:

$$J_D(m) = \frac{1}{2}\left\|u(m) - d\right\|^2 .$$

Also, to ensure the continuity of the geophysical parameter as an *a priori* information, it is possible to modify the misfit function by a multiplicative regularization term (van den Berg et al. 2003), (Abubakar et al. 2004), and (Bulcão et al, 2011):

$$J(m) = J_D(m) R(m).$$

A suitable choice for $R(m)$ is the weighted L_2-norm, which ensures continuity of the velocity model with possible sharp model contrast:

$$R_{WL_2}(m) = \frac{\int\left[\left|\nabla m\right|^2 + \gamma_{k-1}\right]d\Omega}{\int\left[\left|\nabla m_{k-1}\right|^2 + \gamma_{k-1}\right]d\Omega}$$

with $\gamma_{k-1} = J_D(m_{k-1})\delta / \Delta V$ and δ is a parameter defined by the user to control the regularization strength.

Given these remarks, the geophysical parameter may be updated by the steepest descent method,

$$m_k = m_{k-1} - \alpha \nabla J(m)$$

or with a suitable direction by a conjugate gradient method. The value of α is found using some type of line-search technique.

Numerical Experiments

We apply our FWI scheme on synthetic data generated on a velocity model that presents the main features of Santos Basin, offshore Brazil (Fig. 1). This model was built assuming the interpretation presented in Mohriak et al. 2008. Typical values of velocity were used to fill the layers. The targets are located bellow the thick salt layer and our aim was to see up to which point FWI could recover the details of those areas. The model and the data parameters are exhibited on table 1.

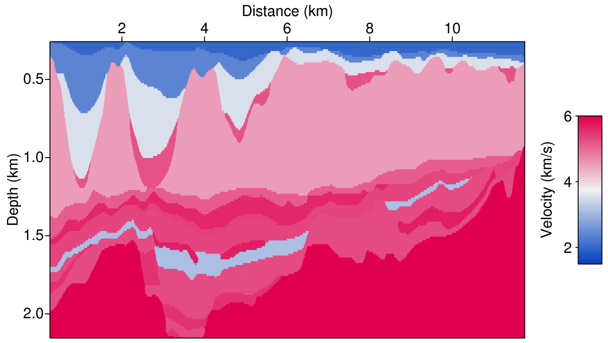

Figure 1: Velocity model based on the Santos Basin. The dimensions were adapted in order to make the numerical experiments feasible.

Table 1: Modeling and inversion parameters

Model dimensions x and z	200x1000 grid points
Grid point interval	12m
Number of shots	236
Number of receivers	957
Shot interval	48m
Receiver interval	12m
Number of frequencies	10
Number of iterations per frequency	35

We use our finite differences code on the frequency domain considering PML boundary conditions all around (Berenger, 1994).

Three initial velocity models were created for our FWI methodology. The first one is strongly smoothed version of the true velocity model. The second one tries to mimic the data obtained from a sonic log after smoothing to match the range of seismic frequencies. The last model is a constant velocity one (v=3.5 Km/s).

The inversions ware performed on the frequency domain in a multi-scale approach starting from 3.4 Hz up to 22.9 Hz (increments of 1.95 Hz). For the smoothed and well based initial models, we ran three times this set of frequencies using the previous iteration result as initial input for the following pass. The results are presented on Figures 2, 3, 4 and 5.

A second pass in the inversion for the constant initial model case did not improve the result obtained in the first loop of frequencies.

Discussion

The desired model was nearly recovered for the first two initial velocity fields. We only observed small artifacts specially located near the edges. We also see an artificial layering bellow the top of the salt as a consequence of internal multiples that appear between the sea bottom and the top of the salt.

One interesting aspect of the results is that the velocity inversions presented in the pre salt region were correctly recovered (Figures 2) even in the absence of any information about this layer on the input model based on the well log.

In relation to the result obtained using the constant initial model, we see that FWI was able to succeed down to the beginning of the salt sequences. After those sequences the result was severely degraded.

Conclusions

We investigate the influence of three starting models on FWI applications on a typical velocity model of Santos Basin, offshore Brazil. We consider a strongly smoothed version of the true model, a well log based model, and a constant velocity field.

The first two cases were able to cope with the complexity of wave-field. Velocity inversions located bellow the salt layer was successfully recovered. Even the absence of those inversions on the well log based initial model did not prevent this good result. In relation to the third initial model, FWI converged to a local minimum away from the true model bellow the starting of the salt sequences. However, it was capable of succeeding in the post salt area.

As we wanted to investigate the best result we could get from each starting model, we considered the most suitable acquisition parameters for FWI. In other words, we assumed the presence of low frequencies and very long offsets.

We also supposed that the same acoustic approximation holds for simulations and inversions (*the inversion crime*). Our next steps will be in the direction of alleviating such assumptions.

Acknowledgments

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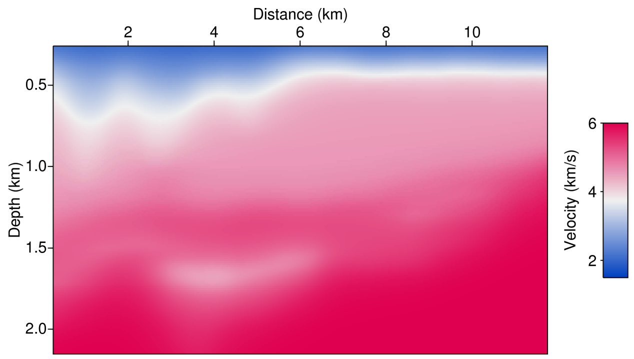
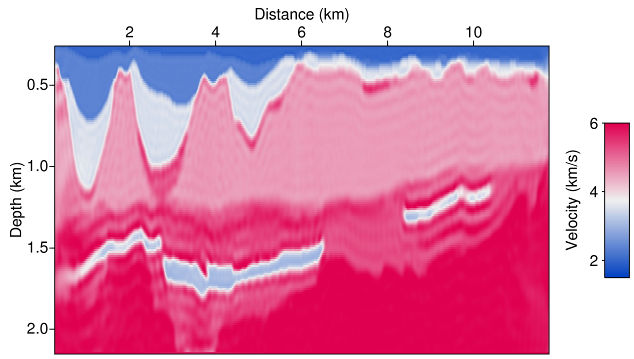
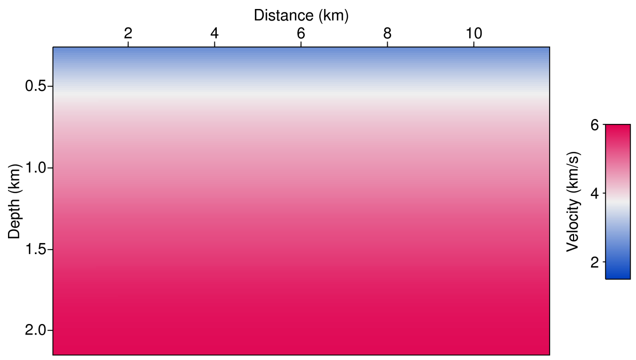


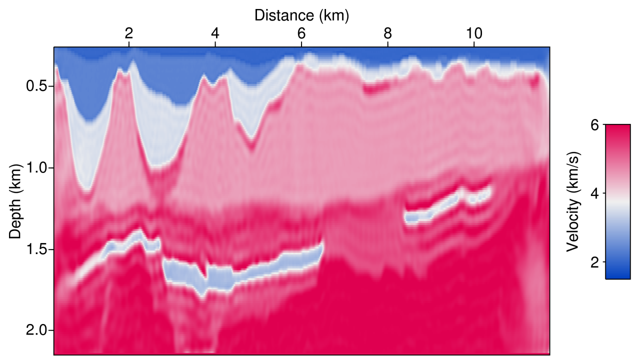
(a) Initial smoothed model



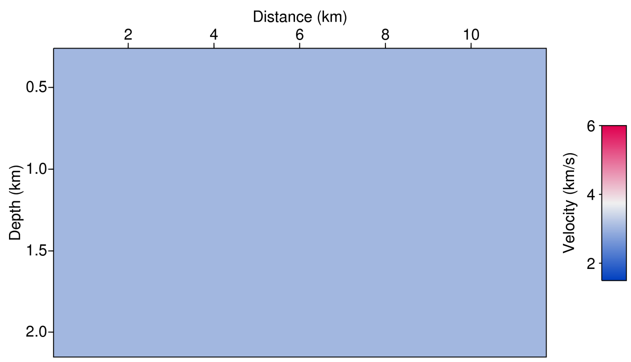
(b) Result for initial smoothed model



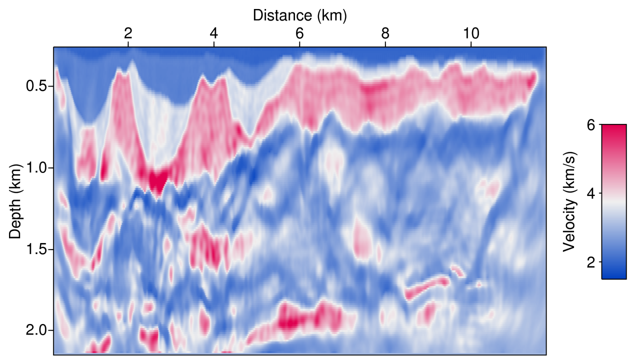
(c) Initial model based on pseudo-well log



(d) Result model based on pseudo-well log

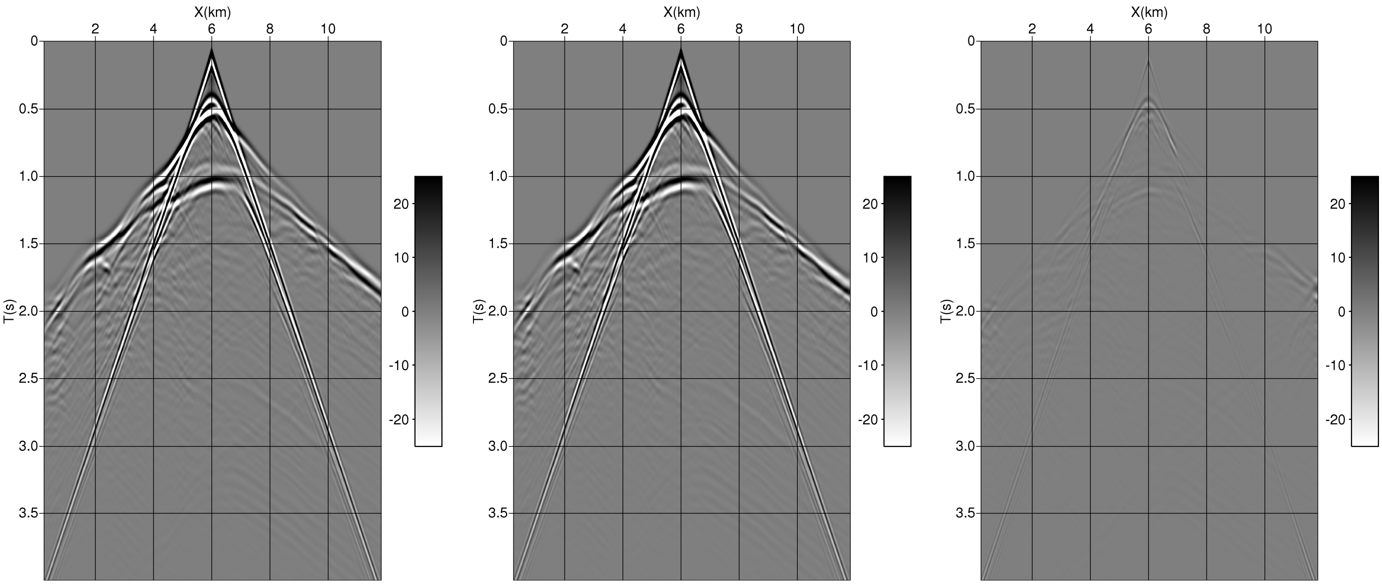


(e) Initial constant model



(f) Result for initial constant model

Figure 2: Results of the FWI considering different initial velocity models.



(a) True model (b) Result for initial smoothed model (c) Difference between shot-gathers

Figure 3: Common-shot gathers.

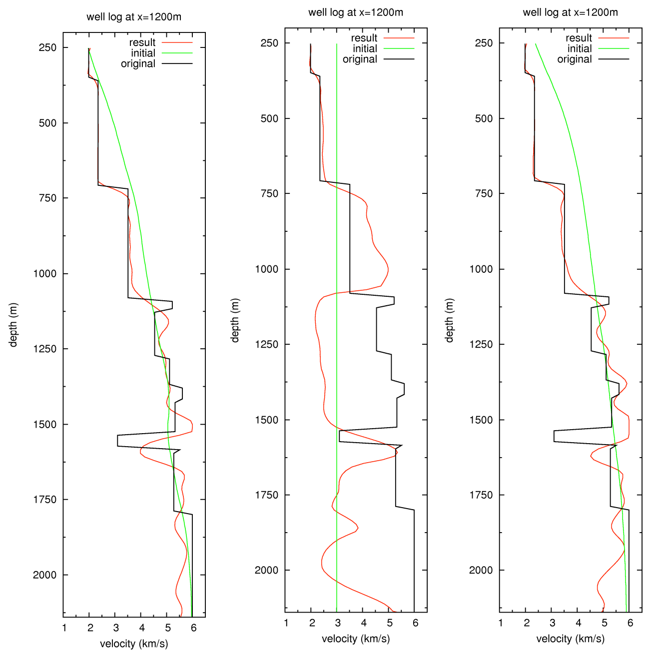


Figure 4: Well profile for the smoothed initial model (on the left), constant initial model (in the middle), and well-profile based initial model (on the right).

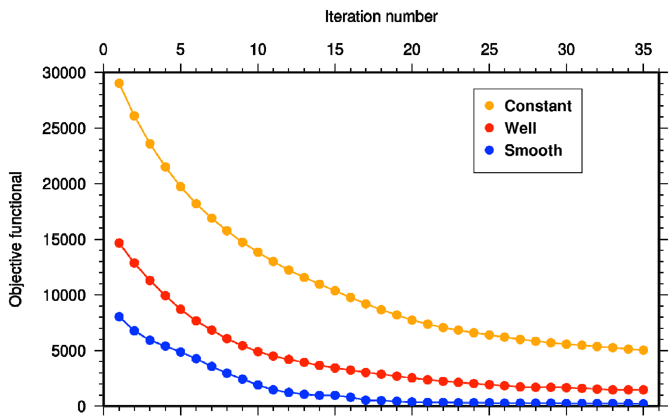


Figure 5: Objective functional for the three initial models and the first frequency considered in the inversion.

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