Estimation of an acoustic velocity model for the CROP M12A seismic line using a gradient-based Full Waveform Inversion

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Outline

➢ Full Waveform Inversion

➢ The CROP M12A seismic profile

➢ Setting of the modelling, the misfit function, and the optimization procedure

➢ Preliminary results
Full Waveform Inversion

- Estimation of a geological macro-model of subsurface from active seismic data by means of:

1) Modelling algorithm
   - Numerical solution of the wave equation (2D acoustic)

2) Misfit function
   - Difference between predicted and observed data (seismograms)

3) Optimization algorithm
   - Iterative procedure to minimize the misfit function

Starting model \( v_0 \)

Predicted data \( d(v_k) \)

New predicted model \( v_k \)

Observed data \( d_0 \)

Misfit evaluation \( F(v_k) = \|d(v_k) - d_0\| \)

Are the optimization criteria met?

Optimization

Final model \( \tilde{v} \)

The CROP M12A seismic profile

- Original dataset
  - 1500 marine seismic shots
  - Source and receivers (180 channels) located at a depth of 8m and 14m respectively, with offset between 125m and 4.5km
  - $dt = 4ms$, and $T = 3s - 4s$ (enough for structures located at shallow depth)

- Dataset considered for FWI
  - 100 shots gathers evenly distributed in 22 km towards the end of the line

Modelling

\[ \ddot{p}(\vec{x}, t) = v(\vec{x})^2 \Delta p(\vec{x}, t) + f(\vec{x}, t) \]

- Explicit, 2nd order in time, finite difference code to solve the 2D acoustic wave equation:
  - \( dx = dz = 25m, nx = 981, nz = 80 \)
  - \( dt = 4ms, T = 2.5s \)
  - \( v(\vec{x}) \) is the 2D acoustic model
  - \( f(\vec{x}, t) \) is the seismic source, whose wavelet is estimated from seabed reflection

Processing on seismic data

➢ The seismograms must be processed:
  ▪ to increase the S/N ratio
  ▪ To reduce the non-linearity of the misfit function
  ▪ because the modelling is 2D acoustic

Processing operations
  1. muting mask
  2. low-pass filter up to 15Hz
  3. trace envelope
  4. trace normalization

Before the processing

After the processing
Design of a robust misfit function

- Mean of all the $L^2$-norm difference between the observed and the synthetic seismograms
- Dedicated processing operator is to reduce the cycle skipping effect and the non-linearity of the optimization problem

$$F(v) = \sum_{s=1}^{ns} \left( \sum_{r=1}^{n^schan} \left( \sum_{k=1}^{nt} \left( \left( G(p(v, t_k, x^s, x^{r,s})) - G(p_0(v, t_k, x^s, x^{r,s})) \right)^2 \right) \right) \right)$$

where:
- \( p(v, t_k, x^s, x^{r,s}) \) are the observed seismograms
- \( p_0(v, t_k, x^s, x^{r,s}) \) are the synthetic seismograms
- \( G \) corresponds to the following processing operations (Galuzzi et al., 2018):
  1. Mute on the diving waves and the shallow reflections
  2. Filtering \([5Hz - 15Hz]\)
  3. Trace envelope
  4. Trace normalization

Inversion procedure

- The inversion grid is the modelling grid without the first four rows (a total of 819x76 unknowns)
- The optimization algorithm used is the steepest descent algorithm
  \[ v_{k+1} = v_k + \gamma_k h_k \]
  - \( h_k = -\nabla_v F(v_k) \) is the descent direction, computed by means of the adjoint method (Plessix, 2006)
  - \( \gamma_k > 0 \) is the step length

- The initial model \( v_0 \) is obtained from a Migration Velocity Analysis (MVA) (Tognarelli et. Al., 2010)

- Due to the non-linearity of the misfit function, the starting model in the FWI procedure plays an important role


Updated model

After 50 iterations of the minimization procedure…

➢ The long-wavelength structure is not significantly changed

➢ The upper part shows the updated velocity values

Value of the misfit function

Difference between MVA and FWI model

Final model
MVA Seismograms

Predicted data

...and difference between the observed and predicted data
FWI Seismograms

Predicted data

Shot 3

Shot 27

...and difference between the observed and predicted data
FWI Common image gathers
Conclusions

➢ An acoustic FWI experience was carried out on a portion of the CROP M12A marine seismic profile acquired in the framework of the Italian Deep Crust Project.

➢ The processing sequence applied to the data is an important step to reduce the non-linearity of the misfit function

➢ Using the gradient-based FWI method we were able to update the velocity model previously obtained by a MVA procedure

➢ The quality of the final model is assessed by a better horizontal alignment of the events in the CIGs

...and future works

➢ Use of the full-wavelet for improving the resolution of the estimated velocity model
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...thank you for the attention!


