The seismic physical modelling laboratory as a tool for design and appraisal of FWI methods

Sergio Romahn and Kristopher Innanen
sergio.romahnreynoso@ucalgary.ca

Introduction

We applied full waveform inversion of PP seismic data recorded through the CREWES seismic physical modelling laboratory facility. Physical modelling represents a potentially unique way of validating and appraising complex methods involving real measurements of seismic waveforms. One key advantage is that we know the subsurface model that we want to solve; therefore, we can monitor model errors almost exactly. Another advantage is that we can control and vary many acquisition parameters. Physical modelling data have particularities that need to be addressed, such as source-receiver directivity and changing waveform with offset. We present an early stage, robust workflow for preparation of raw physical modelling data to use as input to FWI. We evaluated a perspective of FWI where the gradient is approximated for applying on pre-critical reflections using the phase shift plus interpolation (PSPI) migration. We derived non-stationary matched filters from well information to calibrate the gradient. We also iteratively applied Gaussian smoothers to frequency-band fixed migrated data residuals as an alternative form of the frequency multi-scale FWI.

Physical modelling

CREWES laboratory / Transducers / Cut channel

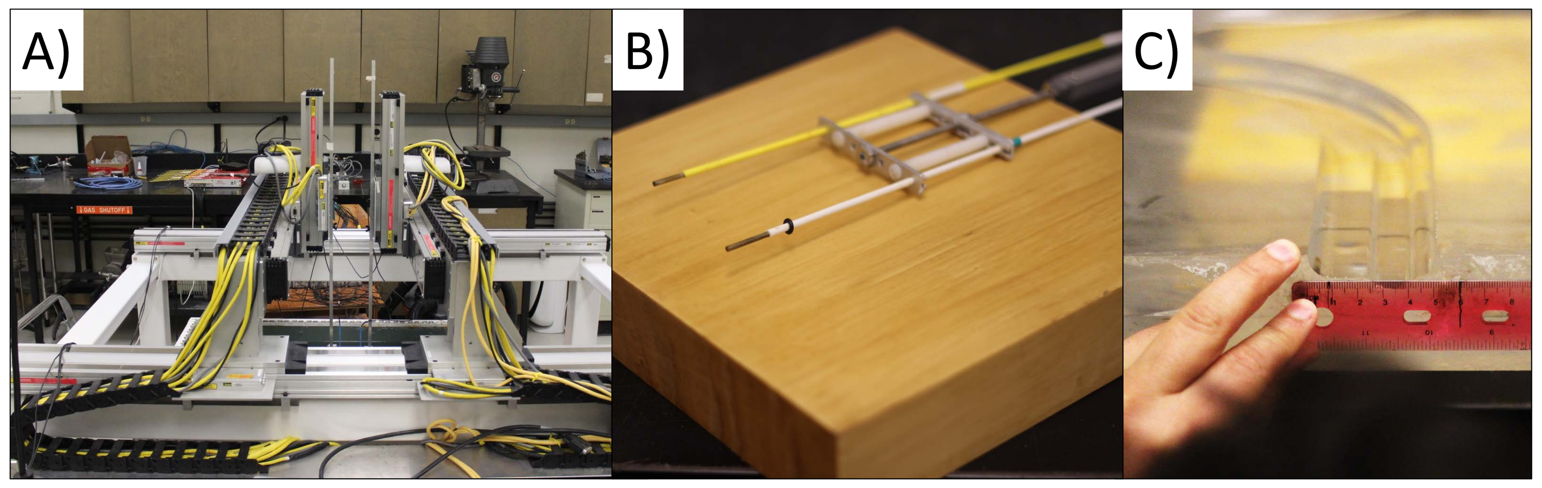

FIG. 1. A) CREWES seismic physical modelling laboratory facility. B) Transducers used as source and sensor. C) Acrylic slab (PLX) with a cut channel. Photographs by Kevin Bertram.

Physical model

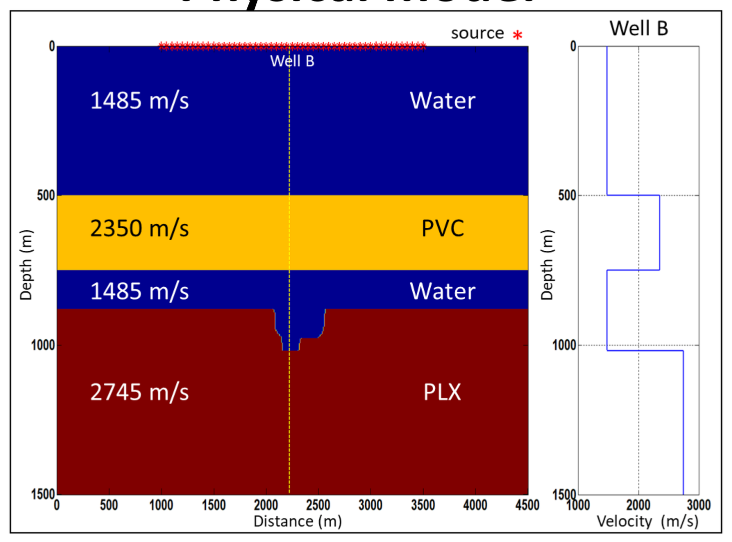

FIG. 2. Horizontal and vertical lengths of 450 mm and 150 mm scale up to 4500 m and 1500 m.

Seismic record

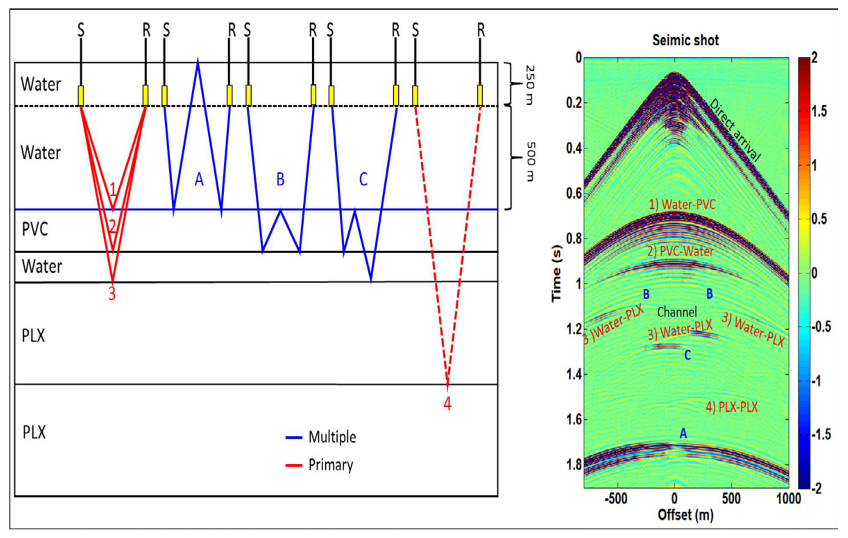

FIG. 3. Seismic shot from physical modelling. The transducers produce dominant frequencies of 500 kHz that scales down to 50 Hz.

Velocity analysis

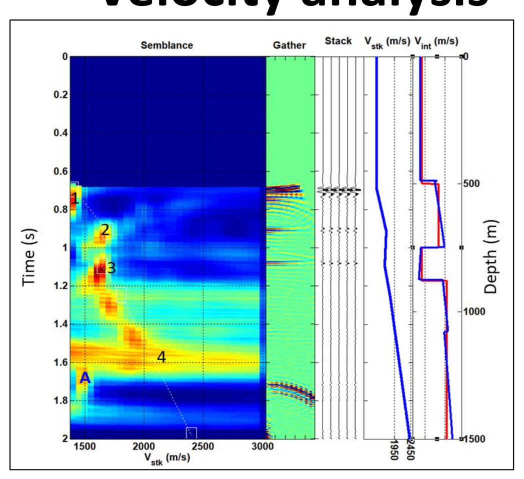

FIG. 4. Picking stack velocities at well C location.

Stack section

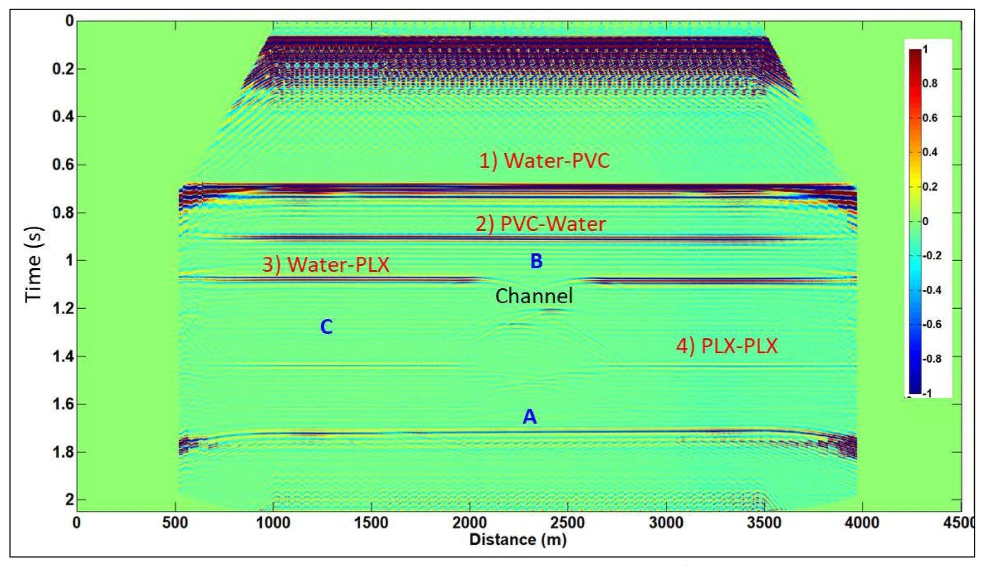

FIG. 5. We used up to 1.4 second to perform the inversion.

Data conditioning

Directivity

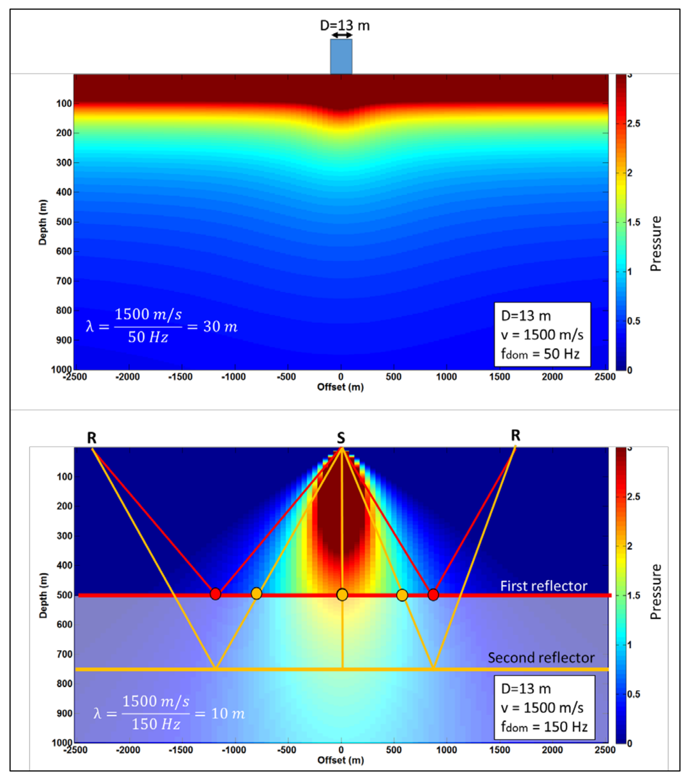

FIG. 6. Radiation pattern for source-receiver transducers for 10 and 30 m wavelengths.

Changing-waveform

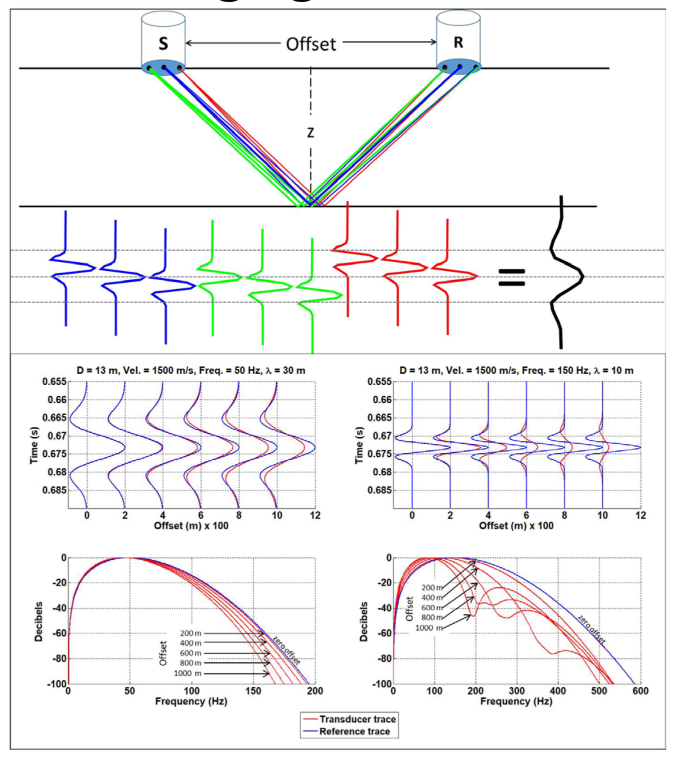

FIG. 7. Transducers work as an array of point sources and receivers, which affects the waveform with offset.

From 3D to 2D geometrical spreading

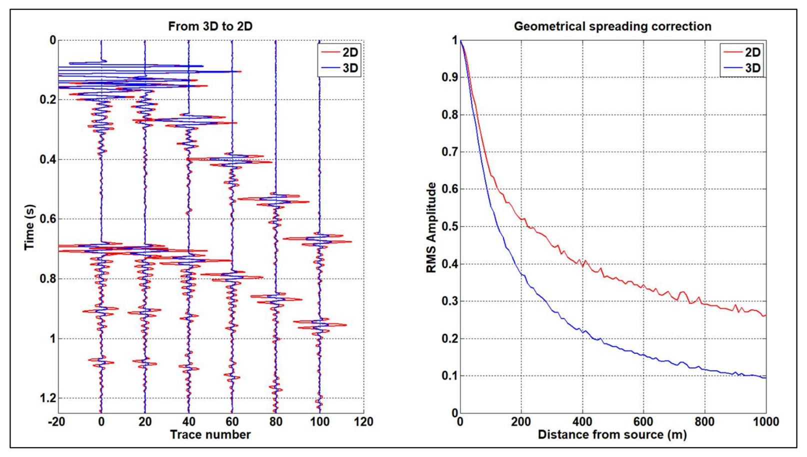

FIG. 8. The approximate correction consists of multiplying the trace by sqrt(t) and convolving with 1/sqrt(t).

Low frequency picks

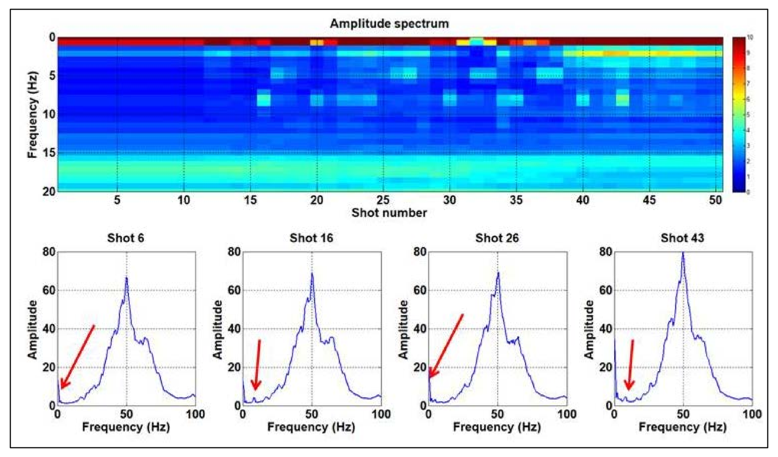

FIG. 9. We applied a high-band pass filter to suppress pick of low frequency.

Wavelet extraction

Wavelet estimation

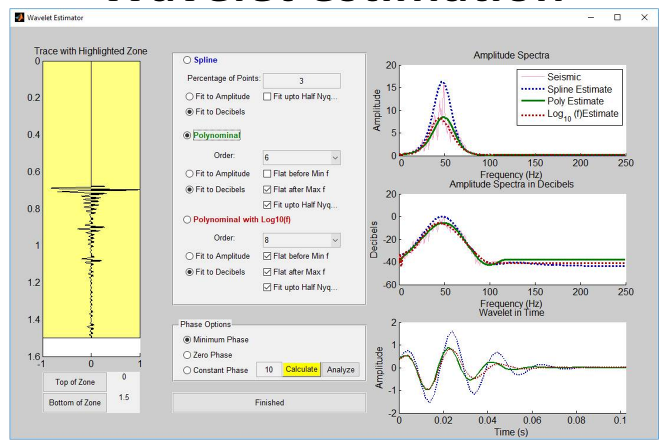

FIG. 10. Estimating a minimum phase wavelet that matches the amplitude spectrum of the seismic shot at the well location.

Wavelet calibration

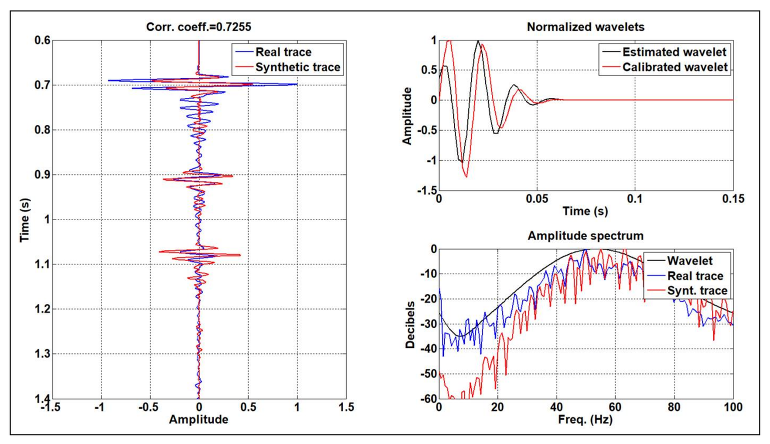

Fig. 11. Matching an observed zero-offset trace to a finite-difference modelled trace to calibrate the wavelet.

Inversion methodology

Initial velocity model

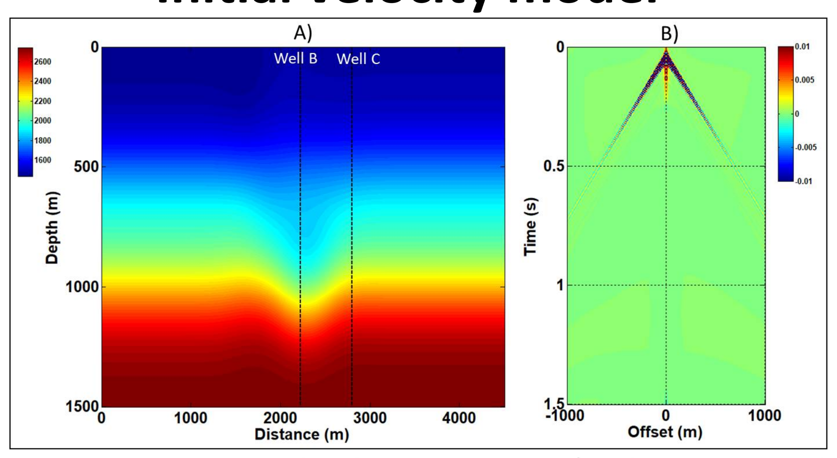

FIG. 12. Smoothed version of the interval velocities derived from the stack velocities.

Gaussian smoother

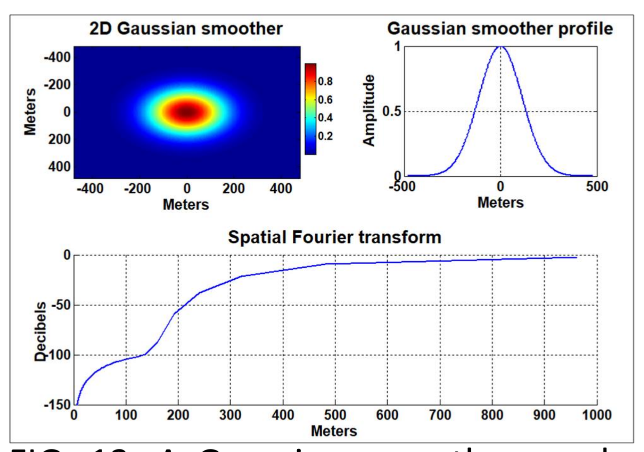

FIG. 13. A Gaussian smoother works as a high-pass wavelength filter.

The gradient was obtained by migrating the whole frequency band (1 -100 Hz) and then applying a Gaussian smoother. The half-width window used in each iteration is shown in Table 1.

Table 1. Half-width used in each iteration

Iteration	1-10	11-20	21-25	26-30
Half-width (m)	160	100	40	20

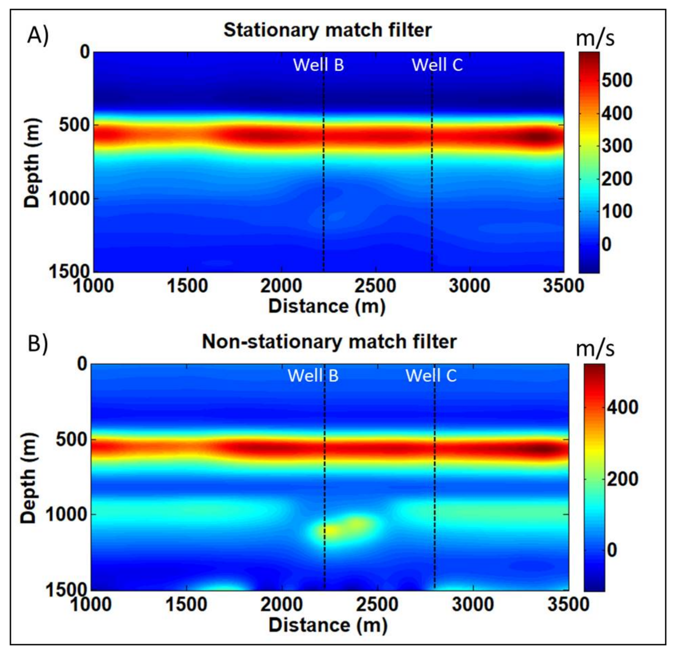

FIG. 14. A) We used the well-calibration technique to scale the gradient. A) Scaled gradient using a stationary matched filter derived from well information. B) Scaled gradient using a nonstationary matched filter.

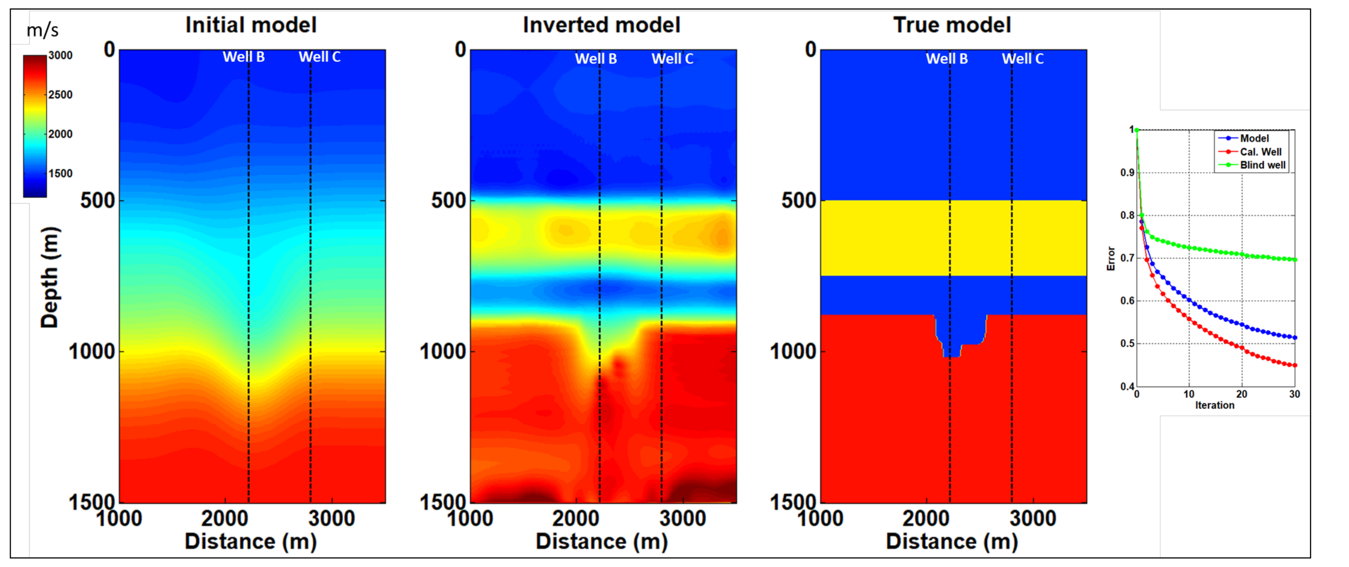

FIG. 15. Inversion result after 30 iterations.

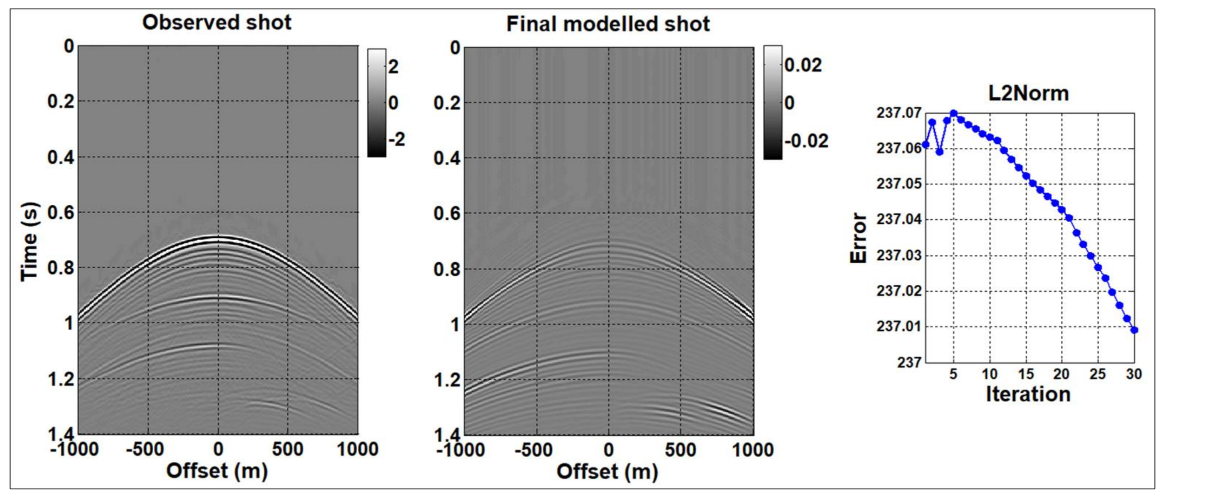

FIG. 16. Comparison between observed and final-modelled shot.

Conclusions

We applied a nonstandard FWI approach to physical modelling data. We evaluated: 1) the use of PSPI migration to obtain the gradient. 2) the use of non-stationary matched filters from well-log velocity to calibrate the gradient. 3) the Iterative application of Gaussian smoothers to frequency-band-fixed migrated data residuals as an alternative to the traditional frequency multi-scale technique. The inversion showed great potential to recover long-wavelength information from reflection seismic data.

Acknowledgements

We thank Kevin Bertram and Joe Wong for their help and advices in the physical modelling laboratory. We also thank the sponsors of CREWES and NSERC (through the grant CRDPJ 461179-13) for their support. Author 1 thanks PEMEX and the government of Mexico for funding his research.

References

Margrave, G. F., Fergurson, R. J., and Hogan, C. M., 2010, Full-waveform inversion with wave equation migration and well control: CREWES Research Report, 22.
Margrave, G. F., Innanen, K., & Yedlin, M., 2012, *A Perspective on Full Waveform Inversion* : CREWES Research Report, 24.
Romahn, S., and Innanen, K. A., 2017, Iterative modeling, migration, and inversion: Evaluating the well-calibration technique to scale the gradient in the full waveform inversion process: SEG Technical Program Expanded Abstracts 2017, 1583–1587.

CREWES

www.crewes.org

NSERC CRSNG

UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
Department of Geoscience