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Report on the PhD manuscript of Anna Adamczyk entitled « Application of full-waveform inversion to land datasets : how much does the acquisition matter? »

Jean VIRIEUX
Professeur Emérite UGA
Jean.Virieux@univ-grenoble-alpes.fr

Téléphone: 33(0) 4 76 63 52 54
Télécopie: 33(0) 4 76 63 52 52
Web: jean-virieux.obs.ujf-grenoble.fr

Unité Mixte de Recherche
UMR 5275
UJF/CNRS/UdS/IRD/LCPC

Grenoble:
Adresse:
1381, rue de la Piscine
38400 Saint-Martin-D'Héres

Adresse postale:
BP 53
38041 Grenoble cedex 9

Observatoire des Sciences de l'Univers de Grenoble

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The manuscript is an original contribution to high-resolution seismic imaging based on the application of the full-waveform inversion (FWI) on rather complex and diverse seismic lines acquired on land: there are very few attempts of the FWI application on land datasets. This PhD work is one of the most extensive investigation I am aware of on these kinds of land datasets.

Obviously, during this research investigation, Anna Adamczyk has illustrated her intellectual capacity for handling signal processing tasks on different seismic recording systems, for understanding both physical and mathematical concepts needed for FWI, aside the computer issues related to this optimization technique based on high-performance computing architectures.

I am very impressed by the different datasets investigated by Anna Adamczyk which are quite different with various difficulties to overcome coming from crooked acquisition, missing low-frequencies, high velocity contrasts and topographic complexities. She has done careful analysis of these difficulties, showing a strong expertise in signal processing, seismic data analysis, wave propagation modeling and optimization strategies. This originality has been recognized by the scientific community through three publications with one about travel time tomography and two about FWI applications. Anna Adamczyk has participated to international conferences such as those from EAGE. I have appreciated her oral presentations at these conferences.

The compact chapter 2 provides a description of the FWI in the frequency domain for a 2D geometry both for the isotropic and anisotropic acoustic propagation. The bottleneck of the FWI is the design of an initial velocity model in order to overcome the cycle skipping issue at the starting frequency. The space devoted to this issue in this chapter is an illustration of the difficulties met by Anna when considering application to land data of large-scale POLCRUST and PolandSPAN experiments. I appreciate that the author keeps short this chapter for a work oriented to data application, but she has put every item needed for this imaging technique.

The chapter 3 describes the case studies and it was the opportunity to see various targets with different scales which is an illustration of the significant work achieved by Anna Adamczyk. The near-surface target is related to quick-clay landslide zone in Sweden for which the acoustic approximation has been considered to be suitable as often done by many other similar studies. The deep reflection seismic profile POLCRUST-01 with standard exploration parameters inducing a lack of low frequencies and

the impressive PolandSPAN dataset with the line PL1-5300 where low frequencies down to 2Hz were emitted, even though 10 Hz geophones were used for recording.

The chapter 4 identifies challenges when applying FWI to land data, specifically coming from the acquisition geometry, the 2D approximation of the wave propagation and the frequency content of the often noisy seismic data.

Describing results on these three datasets will be too long and I shall focus on original investigations achieved by Anna Adamczyk.

Building initial models for FWI in order to mitigate cycle-skipping issues has been a long-standing question during her PhD investigation, even though different new approaches claim that this difficulty can be overcome as mentioned in the manuscript.
A straightforward strategy is the FAT tomography and Anna Adamczyk has used it for the quick-clay landslide zone showing interesting common features with electrical resistivity tomography without the resolution expected for the estimation of the soft combined clay/coarse-grained layers and the granitic bedrock shape in chapter 4, while she was successful to reach enough resolution using FWI for better interpretation in chapter 6. The very clear discussion in chapter 4 related to FAT tomography illustrates the deep understanding of Anna Adamczyk on seismic tomography, especially when high velocity contrasts are found.
Another original strategy comes from the use of models deduced from velocity analysis and PSDM provided by the entreprise ION in the specific case of PolandSPAN where a comparison on the line PL1-5300 between a specific workflow combining PSDM models and heuristic anisotropic parameters for building an initial model is qualified by comparing predicting first-breaks and hand-picked ones: this will be an alternative to the laborious manual pickings for the entire PolandSPAN dataset.

Boosting low frequencies was mandatory for the POLCRUST-01 dataset in chapter 7 which is an interesting and complex dataset with vibroseis sources as well as dynamite shots, complemented by sparse 4.5Hz geophones colocated with 10Hz geophones in the dense setting, which allows a match filtering strategy for increasing the low-frequency content over the dense network using the sparse information. There is an important enhancement of SNR over the frequency range between 5-10 Hz useful for FWI. Curvelet denoising combined with more standard preprocessing workflow illustrates the competence of Anna Adamczyk on signal processing and seismic data analysis. The final FWI result provided along a long profile of more than 200 km is quite interesting: rather precise geometrical relation between Carpathian Mountains and Miocene sediments is imaged with possible faulting structures. Such application of FWI on vibroseis high-frequency seismic land dataset is quite original from my point of view and Anna Adamczyk has the merit to perform this tedious systematic extraction of information of the available seismic data using each piece of records obtained during this experiment.

The PL1-5300 profile of the PolandSPAN dataset with its low-frequency vibroseis source of 2 Hz should be more suitable for FWI, although 10Hz geophones may not provide a good SNR at far distances for going beyond 1.5-2 km depth. The dramatic increase of velocity below 1.5 km is another reason for this depth-penetration difficulty. In this chapter 8, aware of these issues, Anna Adamczyk were able to show that the specific original PSDM workflow for building the initial model was accurate enough for making the FWI working in spite of cycle-skipping issues. Comparison with well logs put some confidence in FWI results and on the FWI workflow designed by Anna Adamczyk.

In the different analysis, Anna Adamczyk has been careful enough to consider the beginning of the record where compressional waves contributes mainly to the seismic signal because she considers only (anisotropic) acoustic propagation. What role plays the topography in such condition: only an elevation problem or a more complicated interaction with waves? What will be the issues for moving to elastic

FWI? What could you expect from multi-component data such as horizontal components. How to integrate geological information in a consistent way into the FWI workflow? What about well information? What is the specific misfit between first breaks from the final FWI model (not the initial one based on the PSDM strategy) and the hand-picked ones? They are few questions to be addressed to the candidate. These questions are on perspectives and future research topics inspired from her quite interesting work.

In her conclusion, Anna Adamczyk provides us the lessons she has taken from the analysis of these different datasets: the importance of the acquisition, the heterogeneous complexity of the different seismic data even over the same target, the diversity of the structures to be imaged which may require specific acquisition design, the human difficulties for doing FAT tomography based on manual pickings. Modern seismology should move to more automatic strategies. Finally, collaborative interpretation of different geophysical quantities is highly recommended. Obviously, Anna Adamczyk has gained scientific maturity during her PhD training, while showing her intellectual capacity of doing advanced research by mastering sophisticated because powerful imaging techniques such that FWI while practising standard techniques such that FAT tomography. This chapter 9 closes the PhD manuscript.

Based on this PhD manuscript where an impressive amount of work has been performed for extracting information of complex seismic data, I recommend that Anna Adamczyk deserves the title of doctor to be awarded by the Institute of Geophysics of the Polish Academy of Sciences.

Jean Virieux
Professeur émérite de l'Université Grenoble Alpes