GeoConvention 2016
Calgary • Canada • March 7-11
OPTIMIZING RESOURCES

Joint Seismic-Airborne EM Inversion for Near-Surface Velocity Model Building

Guy Marquis[1], Weizhong Wang[2], Jide Ogunbo[2], Dawei Mu[2]
[1]Shell International Exploration & Production Company, [2]Geotomo LLC

Summary

We propose here a novel approach to build near-surface velocity models by inverting jointly traveltime and high-resolution frequency-domain airborne EM (FAEM) data. The resulting velocity and resistivity models are forced to be structurally similar through the inclusion of a cross-gradient term in the objective function. Application of the method to coincident seismic and FAEM data from Alberta show that the velocity model from the joint inversion has fewer artifacts and a higher near-surface resolution than that from the traveltime-only inversion but at the expense of the traveltime misfit. The joint inversion velocity model is then used for static corrections and results in improvement in the seismic images.

Introduction

Correcting for near-surface perturbations is one of the most important problems in the processing of land seismic data. These perturbations can be of several origins: e.g. rugged topography, sharp lateral velocity contrasts or low-velocity layers. Over the years, different methodologies have been developed to address these so-called “static” problems such as generalized linear inversion, first-arrival traveltime tomography, refraction traveltime migration or surface-wave dispersion curve inversion. These “seismic-only” approaches generally give good results. They however share the shortcoming of being dependent on seismic data that are optimised to image deeper targets and so not always appropriate for near-surface characterization.

Recent studies have tried to get around this shortcoming by combining the seismic data with data from other geophysical methods that are focused on the near-surface. *Colombo and Keho* [2010] performed structurally constrained joint non-seismic and seismic inversion to solve near-surface problems in Saudi Arabia. *Colombo et al*. [2012, 2015] enforced structural constraints to perform joint inversion of high-resolution EM, gravity and seismic datasets.

In this study, we propose a novel methodology for joint inversion of data sets from seismic and frequency-domain airborne EM (FAEM) data.

Joint Inversion Methodology

For our work’s purposes, the subsurface can be characterized by seismic velocity and electrical resistivity. Although these properties may not have a direct physical relationship between them, their subsurface variations might be coincident (*Zhang and Morgan, 1997*). One way to ensure such structural similarity is to use their cross-gradient which depends on the direction of the property variations rather than on their magnitude.

Defining the cross-gradient t as a structural constraint (*Gallardo and Meju*, 2003, 2004), the joint inversion objective function ∅ becomes:

$$\emptyset(\mathrm{m_e},\mathrm{m_s}) = \omega_\mathrm{e}\left(\|\mathbf{W_e}(\mathrm{d_e}-\mathrm{G_e}(\mathrm{m_e}))\|^2 + \tau_\mathrm{e}\|\mathbf{L}\mathrm{m_e}\|^2\right) + \omega_\mathrm{s}\left(\|\mathbf{W_s}(\mathrm{d_s}-\mathrm{G_s}(\mathrm{m_s}))\|^2 + \tau_\mathrm{s}\|\mathbf{L}\mathrm{m_s}\|^2\right) + \lambda\|t\|^2$$

where the parameters with subscripts e and s correspond to FAEM and seismic terms respectively; m's are the subsurface models, ω's are the misfit scaling factors, d's are the observed data, $\mathrm{G}(m)$ are the model responses, $\mathbf{W}$'s are the data weights, $\mathbf{L}$ is a regularization operator and λ is the cross-gradient weight. The cross-gradient term t is given as (*Gallardo and Meju*, 2003, 2004):

$$t(\log(\mathrm{m_e}), \mathrm{m_s}) = \nabla \log(\mathrm{m_e}(\mathrm{x}, \mathrm{z})) \times \nabla \mathrm{m_s}(\mathrm{x}, \mathrm{z}).$$

Minimising the cross-gradient results in increasing the structural similarity between the two models.

Application to an Alberta data set

We apply our new methodology to collocated seismic and FAEM surveys acquired for Shell Canada in Alberta. The FAEM data used here have been acquired with a Fugro (now CGG) Airborne RESOLVE system, and consist of the real and imaginary parts of the secondary-to-primary field ratio at five frequencies. The instrument was flown on average 35 m above the earth surface.

Our workflow was as follows:

- Starting from a homogeneous half-space, invert separately seismic and FAEM data to bring both models close to their optimal solution. Both inversions converged rapidly.
- Use the two models found above as starting models for the joint inversion and start applying the cross-gradient constraint at the first iteration. Here again, convergence is reached within ten iterations.

The evolution of FAEM misfit,traveltime misfit and cross-gradient during the inversion are shown in Figure 1. The behaviour of the FAEM and traveltime misfits are quite different: while the FAEM misfit decreases steadily then stabilises at the fourth iteration, the traveiltime misfit increases significantly from that of its standalone inversion and then converges to a value higher than for the starting model.The cross-gradient decreases steadily after each iteration indicating that the velocity and resistivity models are becoming increasingly similar. We conclude from these observations that the joint inversion is indeed able to make the two models more similar, essentially at the expense of the velocity model; the resistivity model remains pretty much the same throughout the joint inversion process.

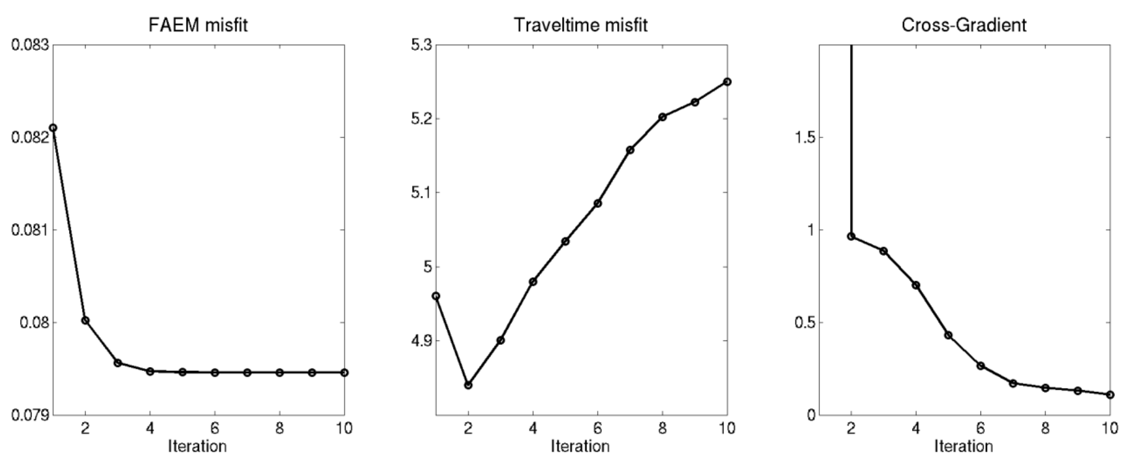

Figure 1. FAEM (left) and traveltime (centre) misfits and cross-gradient (right) as a function of iteration number for the joint seismic-FAEM inversion. The cross-gradient is applied from the first iteration.

The resulting models from the joint inversion are presented in Figure 2. The effect of the joint inversion on the velocity model is easily visible when comparing the velocity models obtained from the standalone traveltime inversion (top) and the joint seismic-FAEM inversion (centre). The traveltime inversion model shows several intermediate-wavelength bumps that are interpreted as ray-path artifacts due to insufficient spatial sampling and the joint inversion effectively removed these artifacts. In addition, the joint inversion model features low-velocity zones between km 56 and 57 (dashed oval in Figure 2) which would never have been found through first-arrival tomography. We also point out the structural similarities between the velocity (centre) and resistivity (bottom) models obtained by the joint inversion, confirming that the cross-gradient constraint indeed makes the models more similar.

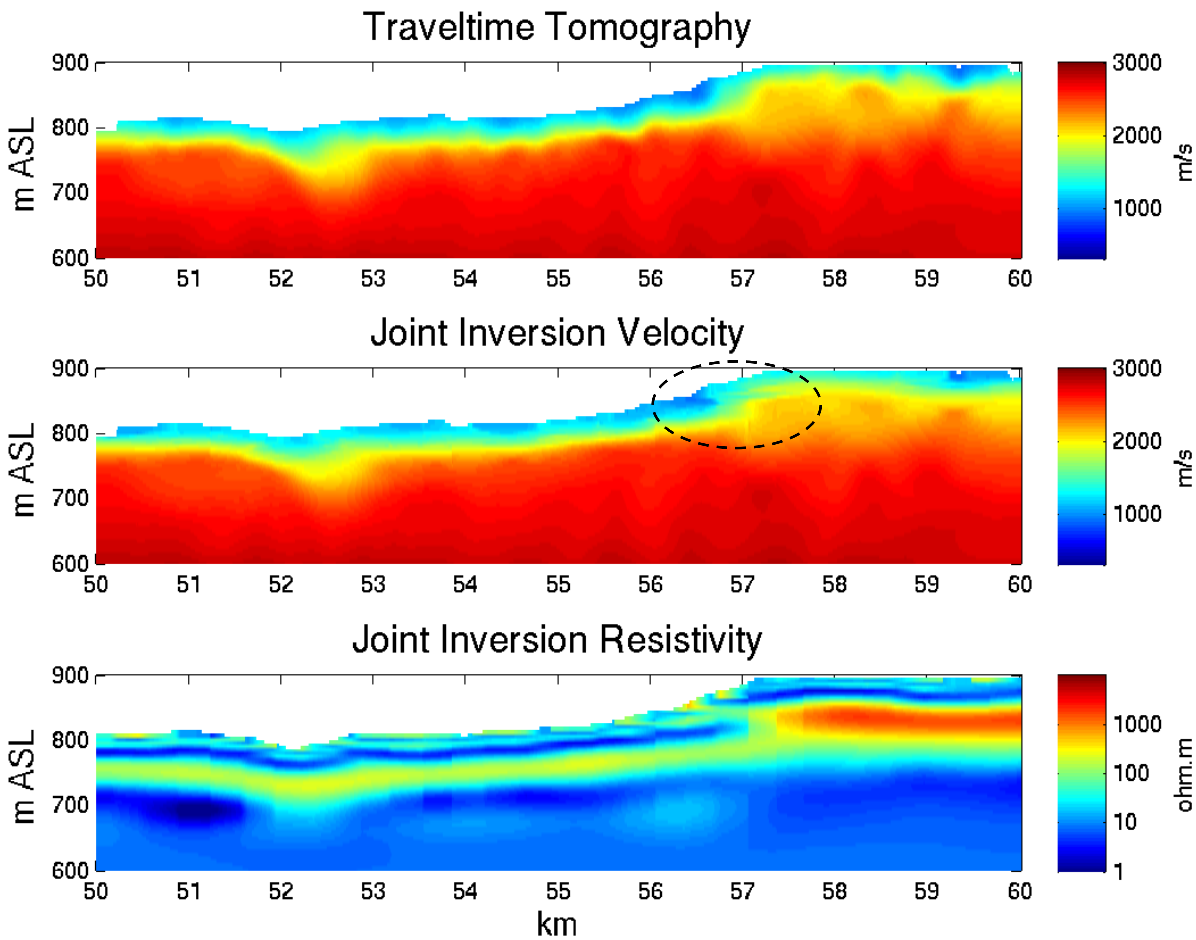

Figure 2. Velocity model from travel-time tomography only (top) and joint seismic-FAEM inversion (centre). Bottom: resistivity model from the joint inversion. The dashed oval shows low-velocity zones.

The near-surface velocity models obtained by traveltime tomography and joint seismic-FAEM inversion are used to compute their respective static corrections. We then processed the original data with the same sequence (except for statics) to produce stack sections, excerpts of which are shown in Figure 3 below. Comparing the two stacks, we observe better reflector continuity and a sharper signal with the joint inversion-based statics (right panel).

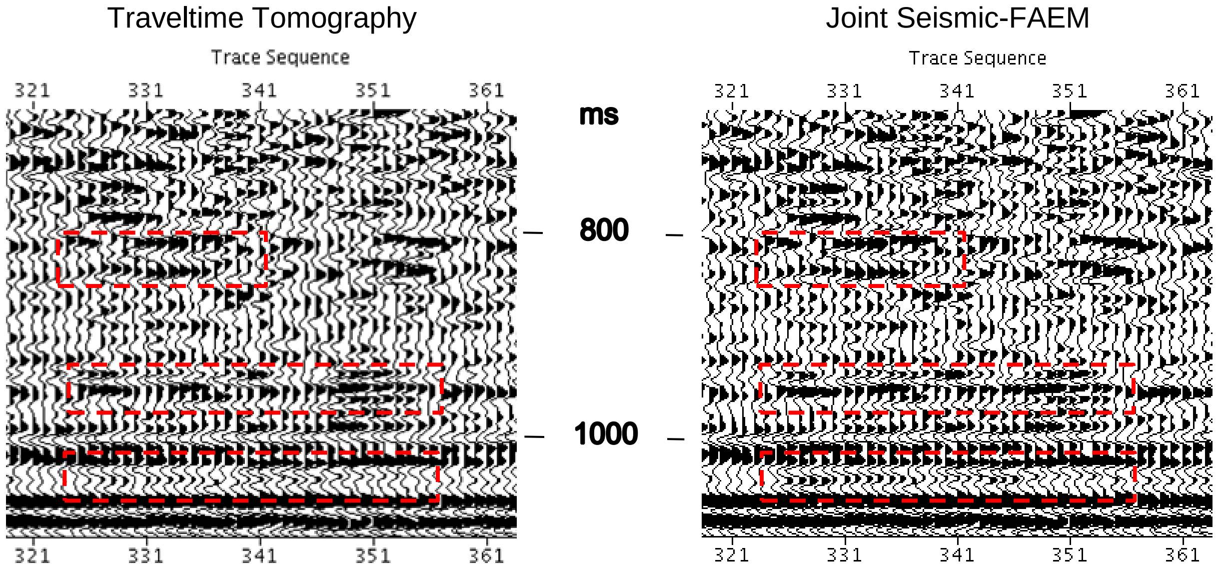

Figure 3. Excerpts from stack sections with statics computed using standalone traveltime tomography (left) and joint seismic-FAEM inversion (right). Boxed areas emphasize imaging improvements.

These early results illustrate the potential of the integration of high-resolution, near-surface focused airborne EM data to complement seismic data. Work on 3D datasets and on the integration of time-domain AEM data are currently under way.

Acknowledgements

We thank Shell Canada Limited for allowing us to present their data.

References

Colombo, D., and T. Keho (2010). The non-seismic data and joint inversion strategy for the near surface solution in Saudi Arabia. SEG Technical Program Expanded Abstracts 2010: pp. 1934-1938. doi: 10.1190/1.3513222.

Colombo, D., G. McNeice, and R. Ley (2012). Multigeophysics joint inversion for complex land seismic imaging in Saudi Arabia, SEG Technical Program Expanded Abstracts 2012: pp. 1-5. doi: 10.1190/segam2012-0441.1.

Colombo, D., G. McNeice, D. Rovetta, E. Turkoglu, A. Sena, E. Sandoval-Curiel, F. Miorelli and Y. Taqi (2015). Super resolution multi-geophysics imaging of a complex wadi for near surface corrections. SEG Technical Program Expanded Abstracts 2015: pp 849-853, http://dx.doi.org/10.1190/segam2015-5841055.1

Gallardo L. A., and M. A. Meju (2003), Characterization of heterogeneous near-surface materials by joint 2D inversion of dc resistivity and seismic data, *Geophysical Research Letters, 30,* 1658, doi:10.1029/2003GL017379.

Gallardo L. A., and M. A. Meju (2004), Joint two-dimensional DC resistivity and seismic travel time inversion with cross-gradients constraints, *Journal of Geophysical Research*, *109*, B03311, doi:10.1029/2003JB002716.

Zhang, J. and F.D. Morgan (1997), Joint Seismic and Electrical Tomography, Symposium on the Application of Geophysics to Engineering and Environmental Problems 1997: pp 391-396. doi: 10.4133/1.2922412.