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Course: Marine Geology

Topic:JOINT INVERSION OF MARINE SEISMIC AND ELECTROMAGNETIC DATA FOR PETROLEUM EXPLORATION

Abstract:

Joint inversion approach for integrating controlled source electromagnetic and seismic full-waveform data for geophysical applications is reviewed. The first step is the joint petrophysical inversion carried out by reconstructing petrophysical parameters such as porosity and saturations instead of the usual geophysical parameters such as resistivity, seismic velocities and mass density. This approach use the strong correlation between the electromagnetic and seismic parameters through the petrophysical relationships. In this approach, the inversion is carried out by employing a regularization function for enforcing the structural similarity between the conductivity and the seismic velocities. The cross-gradient function, which has been shown on many occasions to be quite effective. By using a time-lapse reservoir monitoring example, it show that both joint inversion approaches produce results that are superior to those obtained by disjointed inversions.

1.0 Introduction:

An inversion algorithm for reservoir evaluation and petroleum exploration applications especially for oil and gas has been developed based on Gauss-Newton optimization approach using both EM and seismic data that are jointly inverted using a cross-gradient constraint that enforces structural similarity between the conductivity image and the compressional wave (P-wave) velocity image.

This joint-inversion approach is applied in integrating marine controlled-source electromagnetic data with surface seismic data for subsurface reservoir exploration applications and in integrating crosswell EM and sonic data for reservoir monitoring and evaluation applications, results yield significantly over those obtained from separate EM or seismic inversions. Seismic data inversions have been widely used as the main tool for hydrocarbon exploration because of the high resolution one can obtain from the data analysis. But this inversion is only good at delineating the boundary between hydrocarbons and water because of the low contrast to seismic velocities between the fluids. For this reason it better to constraint the result with the use of collocated marine controlled source electromagnetic (CSEM) surveys. Many numerical modeling algorithms have been developed to interpret such constraint data sets. Although the CSEM interpretation alone can't give the perfect result because of its ambiguities in distinguishing gas-bearing from oil-bearing layers because of the lack of any significant contrast in resistivity. For this reason, the Seismic data and EM data are explanatorily interpreted with two approaches which are linking conductivity and seismic velocity through the petrophysical relationship, e.g., fluid saturation, porosity and the second approach is utilizing the structural similarity between the conductivity and seismic velocity profiles of the targeted regions. Many authors such as Colombo et al., (2018) apply the cross gradient approach for joint magnetotelluric (MT) and seismic data in marine environments for reservoir exploration applications. Other includes the integrating ground-penetrating radar travel time data, cross-hole electrical resistance data, and seismic travel time data for better determination of lithologic boundaries in hydrogeologic studies. The author decisively use the cross-gradient constraint to integrate a frequency-domain, 2.5D EM inversion algorithm with a 2D seismic inversion algorithm on a forward modelling approach. The result from numerical simulation showed that this joint-inversion algorithm significantly reconstructs the conductivity and P-wave velocity image better than results obtained from separate inversions.

2.0 Joint-inversion algorithm:

The EM and seismic data are inverted jointly in an iterative and alternating manner by updating the conductivity and the P-wave velocity models using a constraint that enforces structural similarity between these two models. The idea behind this joint-inversion algorithm is that the seismic data provided the structural information to constrain the inversion of the EM data. On the other hand, the EM data may improve the seismic image such that the fluid type can be identified more easily. The assumption is based on anomaly case where the electrical conductivity model and P-wave velocity model are structurally similar, which is generally a reasonable assumption because conductivity and P-wave velocity are functions of porosity. Crucial features for joint inversion algorithm is simultaneous multi-frequency inversion driven by structural similarity because, by inverting all frequencies simultaneously, all spatial resolutions are included in the inversion from the start. Regularization terms for the electromagnetic and seismic inversions, R_n^{EM} and R_n^{S} respectively, while function R^{CG} is the cross-gradient function that enforces the structural similarity between the conductivity and P-wave velocity images. Understanding the cross-gradient regularization is explained when there is an edge existing in both the conductivity and velocity images at the same location with the same orientation, the cross gradient term is equal to zero whereas if the edges are in different directions, the minimization algorithm will attempt to align the two edges by minimizing the cross-gradient term. Cross-gradient design term is based on the idea that the structural similarity of two images reaches its maximum when the cross gradient of these two images achieves its minimum. Important approach in cross-gradient constraint will not force the edge to appear in the other image, e.g., an oil-water contact is visible only in the conductivity image assuming P-wave velocities are almost the same for oil and water. The cross gradient algorithm will not attempt to develop an artificial boundary between the oil and water in the reconstructed P-wave velocity image furthermore this does not need petrophysical correlations between the conductivity P-wave velocity (fig.1). After conductivity is updated, the same procedure is adopted to update P-wave velocity parameter to complete one Gauss-Newton iteration. In nonlinear inversion of structures with full contrasts, the Gauss-Newton method is preferable because of its faster convergence rate in comparison with the nonlinear conjugate gradient method. Although there is need to calculate the Hessian matrix required to search the minimization direction.

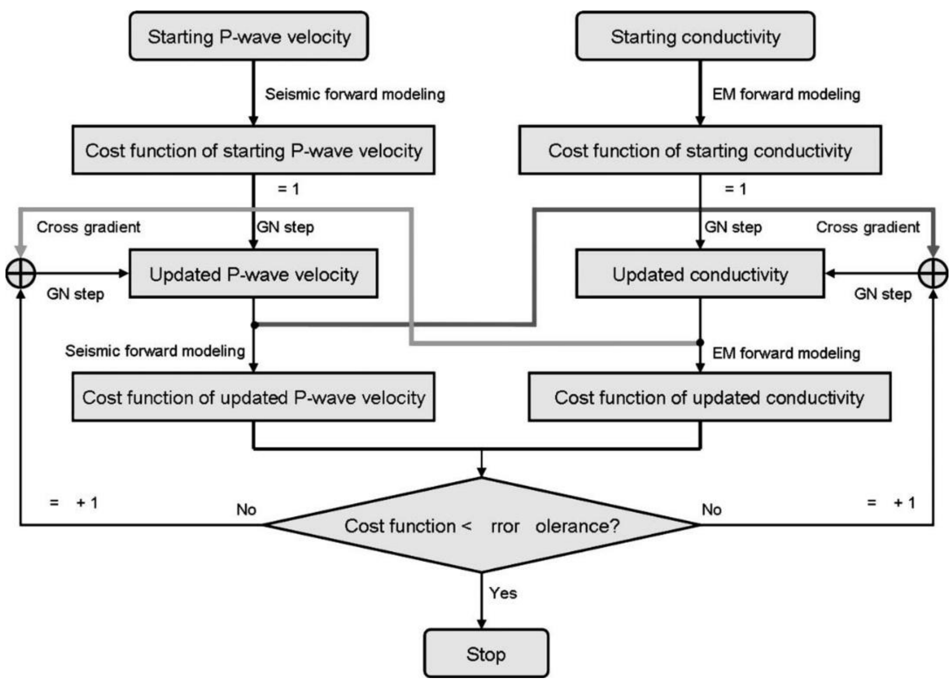

Fig.1: Flowchart of the alternating joint EM/seismic inversion algorithm (Abubakar et al., 2009)

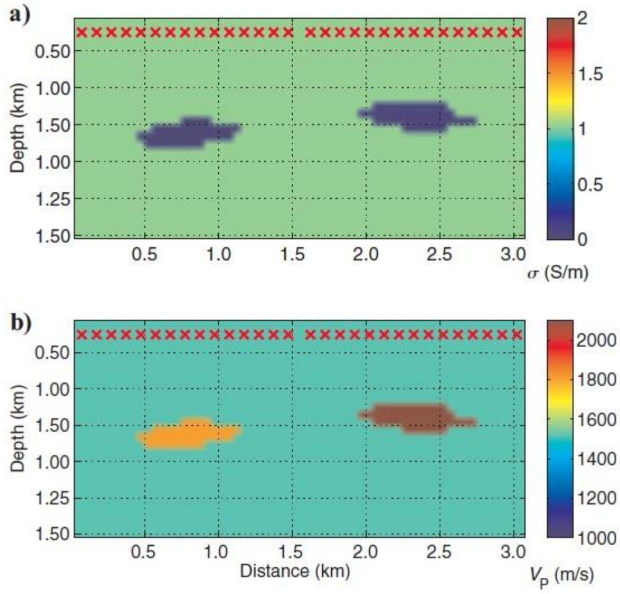

Fig. 2. The true models of the first numerical example. Red X's denote locations of the 30 transmitters and the 30 receivers. (A) True conductivity model. (B) True P-wave velocity model. (Abubakar et al., 2009)

3.0 Numerical Experiments and Conductivity and P-wave velocity Model:

The conductivity model and P-wave velocity model of the first example are represented in Figure 2. In this test example, we have two objects: the left object has a conductivity of 0.01 S/m and a P-wave velocity of 1800 m/ s, and the right object has a conductivity of 0.05 S/m and a P-wave velocity of 2100 m/ s. The background medium has a conductivity of 1 S/m and a P-wave velocity of 1500 m/ s. The data are collected using 30 transmitters and 30 receivers located (fig.2) on the surface of the inversion domain and are uniformly distributed between x = 0 km and x = 3 km. We test the joint-inversion algorithm using three frequencies: 0.5, 1.0, and 1.5 Hz for the EM measurements and 0.6, 1.5, and 2.5 Hz for the seismic measurements. In the inversion algorithm, we assume the objects are located within an inversion domain of 3 x 1.5 km. The grid size is 50 x 50 m. The inverted P-wave velocity model used the separate inversion method which is quite good, further improvement brought by the joint-inversion method is limited in terms of the reconstructed model error (fig3-6).

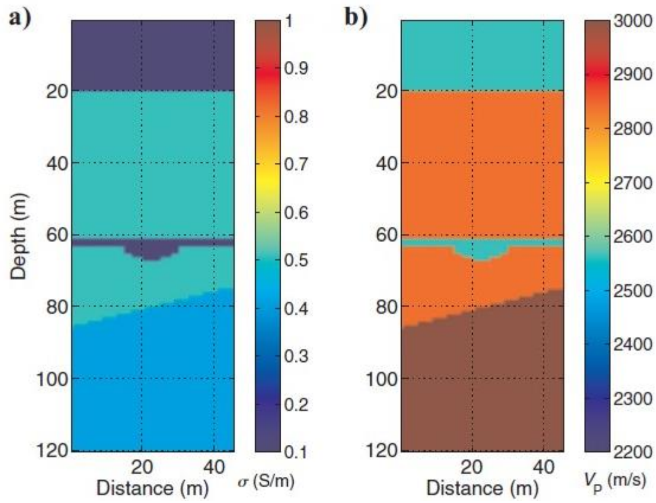

Fig.3: Starting models for the crosswell joint-inversion numerical example. (a) Conductivity model. (b) P-wave velocity model. (Abubakar et al., 2009)

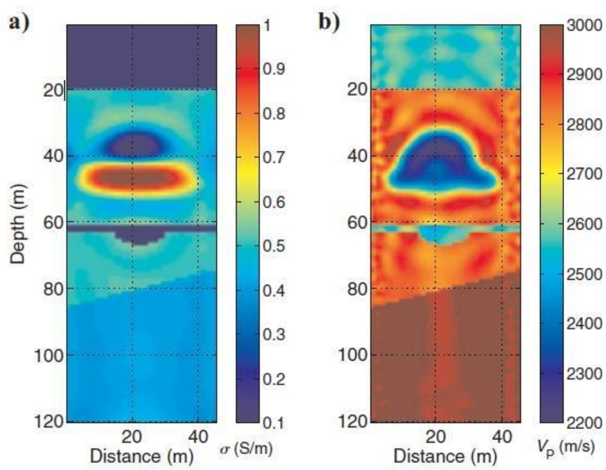

Fig.4: Noise-free separate inversion results of the crosswell example. Operation frequency is 1250 Hz for the EM source and 150 Hz for the seismic source. The $L2$-norm regularization is used. (A) Reconstructed conductivity model. (B) Reconstructed P-wave velocity model (Abubakar et al., 2009)

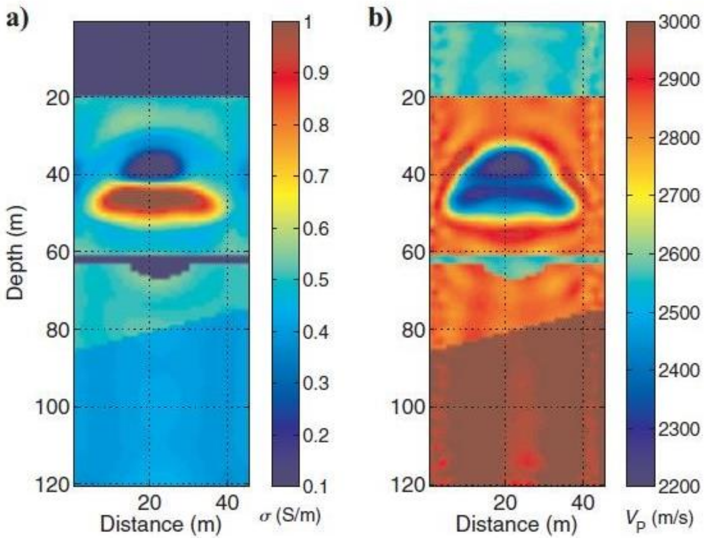

Fig. 5: Noise-free joint inversion results of the crosswell example. Operation frequency is 1250 Hz for the EM source and 150 Hz for the seismic source. The L2-norm regularization is used. (A) Reconstructed conductivity model. (B) Reconstructed P-wave velocity model. (Abubakar et al., 2009)

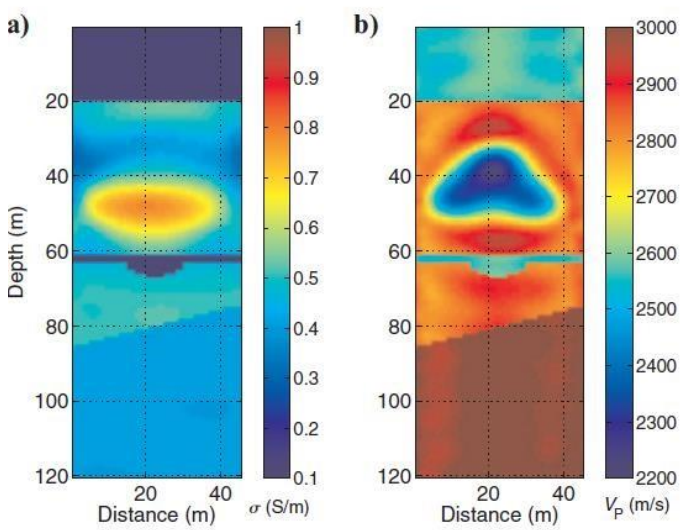

Fig.6: Joint inversion results of the crosswell example with 1% random noise. Operation frequency is 1250 Hz for the EM source and 150 Hz for the seismic source. The *L*2-norm regularization is used. (A) Reconstructed conductivity model (B) Reconstructed P-wave velocity model. (Abubakar et al., 2009)

4.0 Conclusion:

In this joint-inversion algorithm, the EM measurement data and the seismic full-waveform measurement data in the frequency domain are inverted in a coupled manner using a cross-gradient regularization function that enforces the structural similarity between the conductivity model and P-wave velocity model. Because full-waveform data inversion is very nonlinear, the GaussNewton method was used as the optimization algorithm for minimizing the cost function to achieve a faster convergence rate. To improve computation efficiency, an alternatingly iterative approach to jointly invert the EM and seismic data regularized by a cross-gradient term will be suitable. In same light results show that the joint-inversion algorithm improves the inversion results effectively in comparison with the conventional separate-inversion algorithm.

5.0 References

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