Geophysics Bright Spots

Coordinated by Jyoti Behura

Welcome to the latest installment of Geophysics Bright Spots. There are a number of interesting research articles in the last two issues of Geophysics. Here is a list of what piqued the editors' interests.

Protective actions in earthquake early warning systems

Earthquake early warning (EEW) systems are becoming increasingly available throughout the world. The systems are largely developed by geophysicists, technicians, and engineers. We know through social science research that when people are confused about alerts, they tend to wait, do nothing, or take less than optimal protective actions. To help support developers of EEW systems, McBride et al. authored "Evidence-based guidelines for protective actions and earthquake early warning systems." The authors present a framework on how to determine what protective action advice should be shared in messaging. The framework provides an evidence-based approach to decide what actions people should take to protect themselves when they receive an alert.

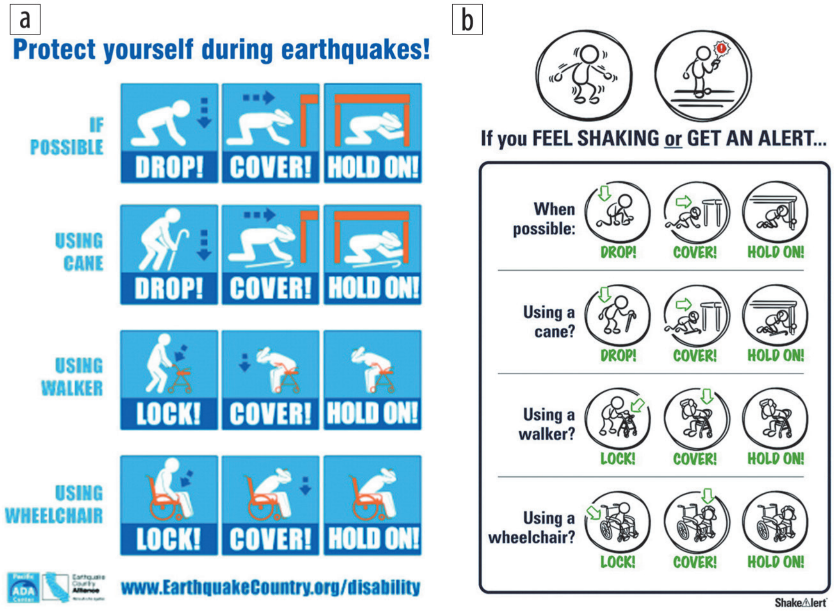

Figure 1. (Figure 5 from McBride et al.) (a) The original figure from the ShakeOut campaign. (b) The redesigned image for ShakeAlert is meant to reach a more diverse segment of the population with a range of abilities so they can take recommended protective actions.

Different nations have unique considerations for optimal protective action. Some recommend drop, cover, and hold on, while others opt for evacuation. The authors state that the main factors for consideration include: (1) social, cultural, and environmental context such as the people present, their social roles, and the type of building in which they are located; (2) demographic and experiential variables such as gender, age, and previous history with earthquakes; and (3) magnitude and intensities that influence the duration and impact of the earthquake. They review earthquake injury reports, EEW literature, protective action and communication theories, and behavioral research to determine what factors can guide decision making when developing protective action guidelines. Although they examine data from around the world, they focus largely on evidence-based recommendations for the U.S. system, ShakeAlert (Figure 1). This provides a timely case study for understanding how people receive and respond to EEW messages, given its recent public rollouts in California, Oregon, and Washington. Their research suggests that drop, cover, and hold on is the best advice for most but not all situations in the ShakeAlert states.

Deep learning surrogate of global optimization

Seismic acoustic-impedance (AI) inversion is the process of transforming seismic reflection data into a quantitative rock-property description of a reservoir. The inversion is highly nonlinear, especially when large AI contrasts are present, leading to issues with local minima. Therefore, conventional gradient-based techniques likely will be trapped in local minima and produce inaccurate results. Global optimization, on the other hand, is a gradient-free technique that can jump out of local minima of a nonconvex misfit function. In particular, multimutation differential evolution (MMDE) is a novel global optimization technique designed for inverse problems with high-dimensional model space. Despite reports of successful applications in seismic AI inversion problems, the efficiency of MMDE can be considered low when dealing with problems with a large number of traces, especially in 3D cases. In "Global optimization with deep-learning-based acceleration surrogate for large-scale seismic acoustic-impedance inversion," Gao et al. present an inversion technique based on MMDE and supervised deep learning (DL). It uses MMDE to invert for AI models of a few traces to generate a data set for DL. DL is used to accelerate and then surrogate MMDE. Because the time-consuming MMDE inversion procedure can be avoided for processing most of the traces, the method has an advantage over MMDE in efficiency. The authors apply the technique to 3D field data and compare the results to existing methods (Figure 2).

Low-cost DC resistivity meter for humanitarian geophysics applications

Insufficient access to safe drinking water is one of the most challenging global humanitarian issues. Near-surface geophysical surveying, especially using the direct current (DC) resistivity method, has long been applied to address the challenges of locating new groundwater resources and optimizing drilling locations.

The capital costs of procuring most commercial-grade DC resistivity systems forms a barrier for many would-be practitioners throughout the world. The development of low-cost microcontrollers and the widespread availability of cheap electronic components raise the possibility of developing low-cost geophysical instrumentation with open-source designs and software solutions to circumvent capital cost issues. In "Development and validation of a low-cost direct current resistivity meter for humanitarian geophysics applications," Sirota et al. show how they alter an existing low-cost DC resistivity meter design to improve its usability in different geologic settings. They develop a modular Raspberry Pi data-logging system to improve the unit's functionality and ensure data integrity.

Figure 3 shows the setup of the instrument. They test the instrument in a Geoscientists *without* Borders project, jointly run by the Colorado School of Mines (CSM) and Université d'Abomey-Calavi (UAC). A key project component involves CSM and UAC students constructing, validating, and using low-cost DC resistivity meters for fieldwork. The fieldwork aims to better characterize and monitor the health of a local aquifer used as a groundwater source for communities in the Cotonou region. The low-cost instruments are successfully used alongside a commercial resistivity meter to acquire data for 2D inversion of aquifer hydrostratigraphy, indicating the presence of a clay-sand contact. The costs of the redesigned instrument and data logger are US$177 and $108, respectively, with future cost reductions possible.

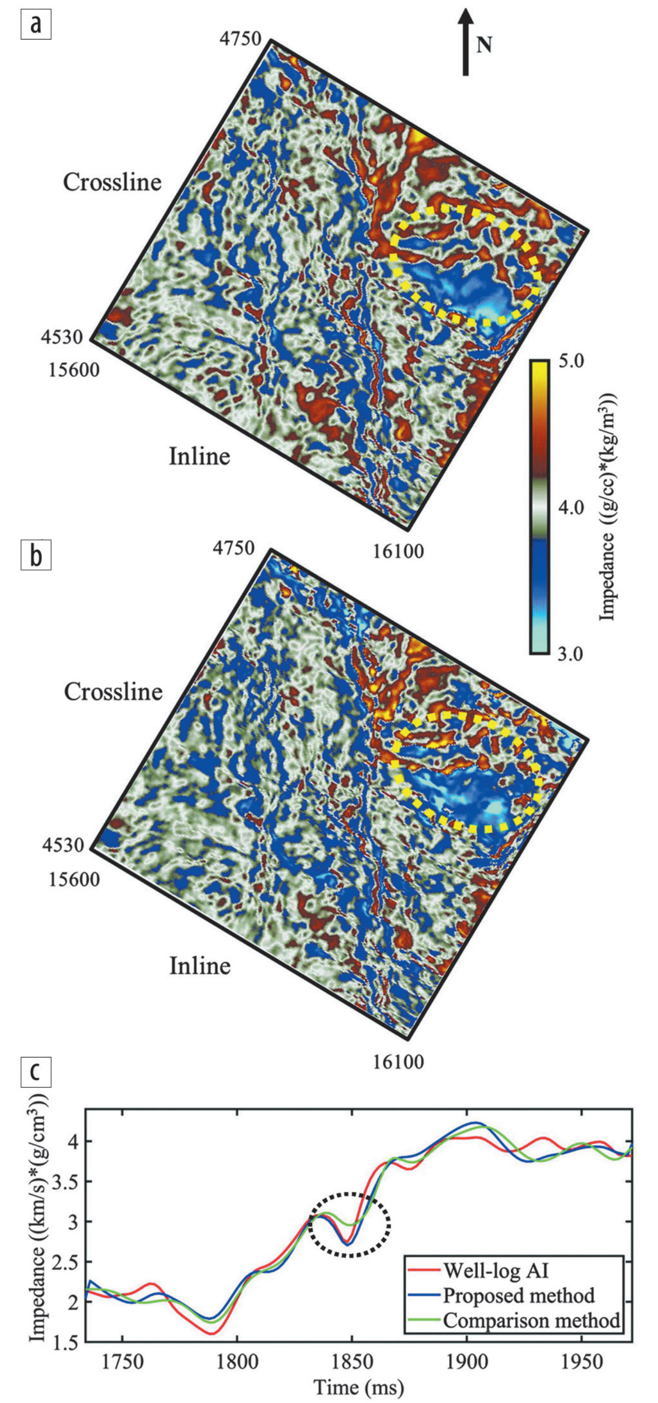

Figure 2. (Figure 19 from Gao et al.) Comparison of the proposed method with existing methodology. (a) and (b) The AI slices along horizon 1 correspond to the built AI models of the proposed method and the comparison method, respectively. (c) The comparison of well-log AI curves and built AI models corresponding to the well location. Inside the dashed yellow ellipses in (a) and (b), the AI interface can be clearly observed. The proposed method can build AI models with better lateral continuity, whereas the comparison method can build AI models with higher resolution. In addition, as shown in the dashed black ellipse, the built AI model of the proposed method is more accurate than that of the comparison method.

An alternate view of the Marchenko focusing function

Marchenko redatuming and imaging methods deal with internal multiples in a data-driven way. At the core of these methods lies the so-called Marchenko focusing function, which consists of a standard primary focusing operator (defined in a macromodel), supplemented with a multiple coda, derived from the reflection response at the surface. Underlying assumptions are that evanescent waves can be neglected and up/down decomposition is possible throughout the subsurface. In "On the relation between the propagator matrix and the Marchenko focusing function," Wapenaar and de Ridder propose a different view of

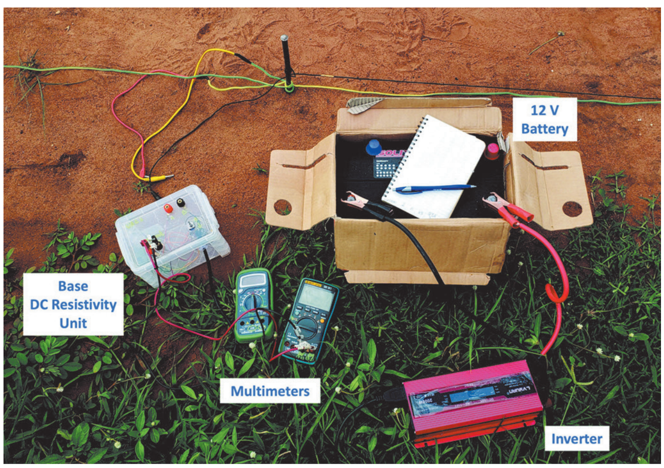

Figure 3. (Figure 4 from Sirota et al.) Field setup of the low-cost DC resistivity system. The current injection box (clear plastic) is plugged into the red power inverter (connected to a standard 12 V car battery) and is attached to the multimeter being used as an ammeter. The other multimeter is used as a voltmeter.

the Marchenko focusing function. They start by reviewing the well-established concept of the propagator matrix. This matrix propagates the full wavefield, from one depth level to another. It implicitly accounts for downgoing, upgoing, propagating, and evanescent waves and avoids the numerical complications of the square-root operator (typical for one-way wavefield extrapolation).

Next, they show that the Marchenko focusing function can be defined as a specific combination of two elements of the propagator matrix. By defining the Marchenko focusing function in this way, it inherits the advantages of the propagator matrix. This may ultimately lead to more general Marchenko redatuming and imaging methods, which account for refracted waves in high-velocity layers, remain valid in caustics, and have the ability to accurately image steep flanks.

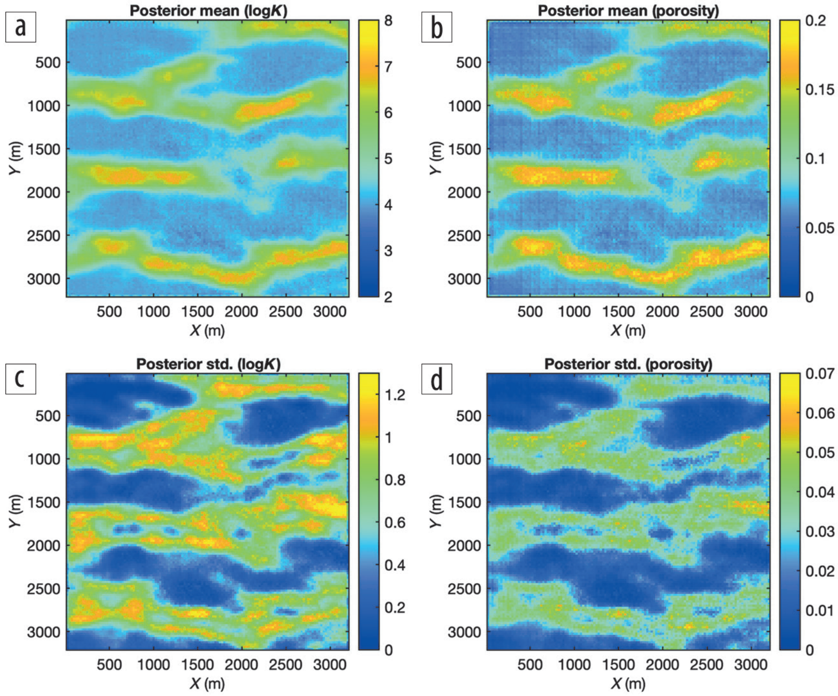

Figure 4. (Figure 18 from Liu et al.) Seismic history matching for the prediction of porosity and permeability using model and data dimension reduction. (a) Posterior mean of log permeability models. (b) Posterior mean of porosity models. (c) Posterior standard deviation of log permeability models. (d) Posterior standard deviation of porosity models.

Uncertainty quantification in stochastic inversion

Quantifying the uncertainty in subsurface reservoir models is a crucial step in decision-making processes for resources exploitation such as hydrocarbon production, carbon sequestration, and groundwater management. Uncertainty quantification requires the estimation of the probability distribution of the model variables, conditioned on geophysical and borehole measurements or its approximation, through as set of multiple model realizations that are consistent with the available data. This statistical process is computationally challenging for large-scale geophysical inverse problems with high-dimensional model and observation spaces. Recent advances in DL, such as variational autoencoder and generative adversarial networks, enable reducing the computational cost of the inverse problem by introducing sparse representations of high-dimensional variables and efficiently performing the inversion in low-dimensional spaces. However, the dimensionality reduction may lead to information loss and inaccurate quantification of the model uncertainty. In "Uncertainty quantification in stochastic inversion with dimensionality reduction using variational autoencoder," Liu et al. comprehensively investigate the impact that the dimensionality reduction of model and data spaces obtained with deep generative networks might have on uncertainty quantification in nonlinear inverse problems. The study focuses on stochastic inversion of seismic data and seismic history matching (Figure 4). It shows that the model reduction leads to underestimation of the model uncertainty, whereas the data reduction leads to overestimation of the model uncertainty. The bias in the uncertainty quantification depends on the dimensionality of the reduced space. The authors show that there is a trade-off between computational efficiency and accuracy of the uncertainty quantification. TLE

References

Gao, Z., W. Yang, Y. Tian, C. Li, X. Jiang, J. Gao, and Z. Xu, 2022, Global optimization with deep-learning-based acceleration surrogate for large-scale seismic acoustic-impedance inversion: Geophysics, **87**, no. 1, R35–R51, https://doi.org/10.1190/geo2021-0070.1.

Liu, M., D. Grana, and L. P. de Figueiredo, 2022, Uncertainty quantification in stochastic inversion with dimensionality reduction using variational autoencoder: Geophysics, **87**, no. 2, M43–M58, https://doi.org/10.1190/geo2021-0138.1.

McBride, S., H. Smith, M. Morgoch, D. Sumy, M. Jenkins, L. Peek, A. Bostrom et al., 2022, Evidence-based guidelines for protective actions and earthquake early warning systems: Geophysics, **87**, no. 1, WA77–WA102, https://doi.org/10.1190/geo2021-0222.1.

Sirota, D., J. Shragge, R. Krahenbuhl, A. Swidinsky, N. Yalo, and J. Bradford, 2022, Development and validation of a low-cost direct current resistivity meter for humanitarian geophysics applications: Geophysics, **87**, no. 1, WA1–WA14, https://doi.org/10.1190/geo2021-0058.1.

Wapenaar, K., and S. de Ridder, 2022, On the relation between the propagator matrix and the Marchenko focusing function: Geophysics, **87**, no. 2, A7–A11, https://doi.org/10.1190/geo2021-0511.1.