Improved imaging of electrically conductive solute plumes using a new strategy for physics-based regularization of resistivity imaging problems

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The ill-posed nature of image reconstruction from sparse and limited data requires that constraints be defined to make the inverse problem tractable. A common approach to stabilizing the inversion is to utilize Tikhonov style regularization to modify the model space such that solutions with characteristics that are deemed to be appropriate for a particular application are produced. Filters on model space are typically applied to minimize metrics such as the norm of the parameter values or derivatives, which results in images that are, for example, optimally "small" or "smooth". These a priori constraints, however, do not take into account the physical processes and phenomena that generated the particular distribution of parameters that are being imaged. To address this problem, a contrasting approach to estimation called "coupled inversion" has recently gained interest in the field of geophysical monitoring. In this case, observational data are used to directly constrain the hydrologic parameters in a numerical simulator of the physical process that is ultimately responsible for creating the particular distribution of state parameters being targeted in the imaging problem. While this approach allows for the physics of the process being imaged to be integrated into the inverse problem, it applies a hard constraint in the sense that the resulting images must conform to the behaviors allowed by the process simulator, even when the data suggest that the simulator may be conceptually or numerically incorrect. To address the limitations of both of these methodologies, we have formulated an alternate strategy whereby the physics of the process generating the target distribution is integrated directly within a standard Tikhonov regularization scheme. We have found that our methodology allows for the reproduction of images with higher fidelity and improved plume morphology than either standard or coupled inversion, even when the conceptual model underlying the inversion is incorrect. We therefore suggest that our new approach to physics-based inversion allows for the most flexible approach to reconstructing images constrained to the physics of a process when the understanding of that process is not yet fully developed or aspects of the problem, such as initial or boundary conditions are unknown.

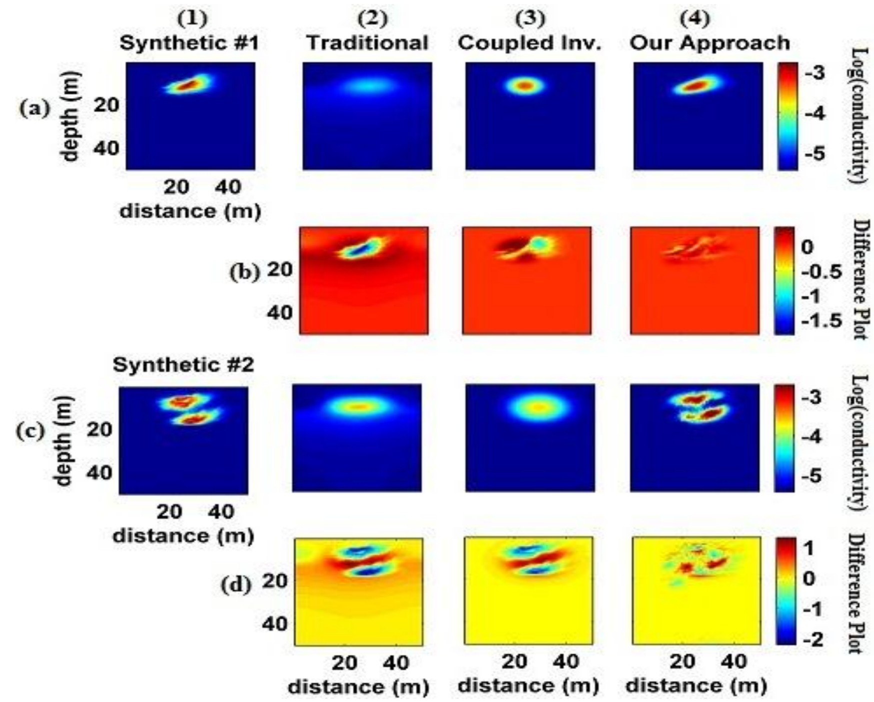

Figure 1: Comparison of a true plume (1) to images obtained via three different inversion strategies: traditional Tikhonov smoothness constraint (2), coupled inversion (3), and our physics-based basis-constrained inversion (4). Tomograms in row (a) are for synthetic plume #1 and those in row (c) represent synthetic plume #2. Rows (b) and (d) are their respective difference plots.

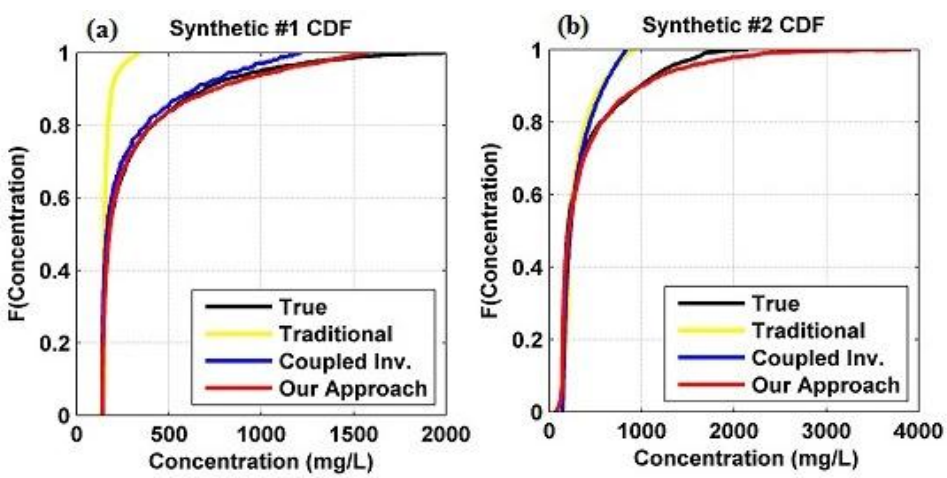

Figure 2: Comparison of the commulative distribution curves of estimated concentration for the three different inversion strategies: (a) synthetic plume #1 and (b) synthetic plume #2.