Combined ERT and IP modelling for monitoring DNAPLs: preliminary results

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Introduction

Successful remediation of sites contaminated with dense non-aqueous phase liquids (DNAPLs) requires effective characterization and monitoring of the DNAPL source zone over time (Figure 1 presents a simulated subsurface distribution of DNAPL). In this framework, geoelectrical methods exhibit significant potential, particularly in time-lapse mode, which has seen recent advancements such as 4D inversion.

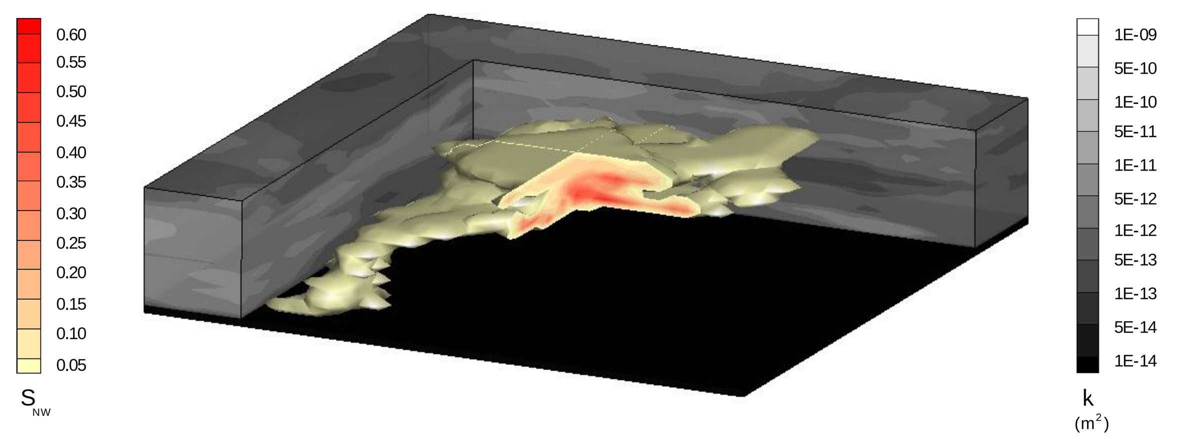

Figure 1. 3D model showing distribution of DNAPL flowing within a heterogeneous medium

Electrical resistivity tomography (ERT) and induced polarization (IP) techniques have been used to map DNAPLs (e.g., Cardarelli and Di Filippo, 2009; Johansson et al., 2015). As DNAPLs may have increased IP signatures in cases where DC-geoelectrical anomalies are relatively weak, the combined use of ERT and IP holds the promise of improved DNAPL imaging. However, the mechanisms that generate the IP signatures of DNAPLs are not fully understood with a significant and active field of research related to understanding and improving IP petrophysical relationships and modelling tools (e.g., Schmutz et al., 2010).

In this work, we are looking to extend our recent research in DNAPL mapping by ERT and explore the potential of combined time-lapse ERT and IP techniques for monitoring DNAPL source zone remediation.

DNAPL-ERT Linkage Model

A linkage methodology is being developed to couple DNAPL3D, a fully validated multiphase flow model that simulates DNAPL release and remediation scenarios (Grant and Gerhard, 2007), with IP4DI, a geoelectrical model that simulates time-lapse ERT, time-domain IP and spectral IP (Karaoulis et al., 2013). A DNAPL-ERT coupled model has already been developed (Power et al., 2013). As shown in Figure 2, the key hydrogeological parameters (including permeability, porosity, clay content, and evolving air/water/DNAPL contents) are converted to the corresponding geoelectrical parameters (i.e., resistivity) by integration of various hydrogeological and petrophysical relationships (e.g., Berg, 2007). Current work is exploring the extension of this linkage methodology to link DNAPL and IP model parameters and permit modelling of IP signatures from DNAPL spill scenarios.

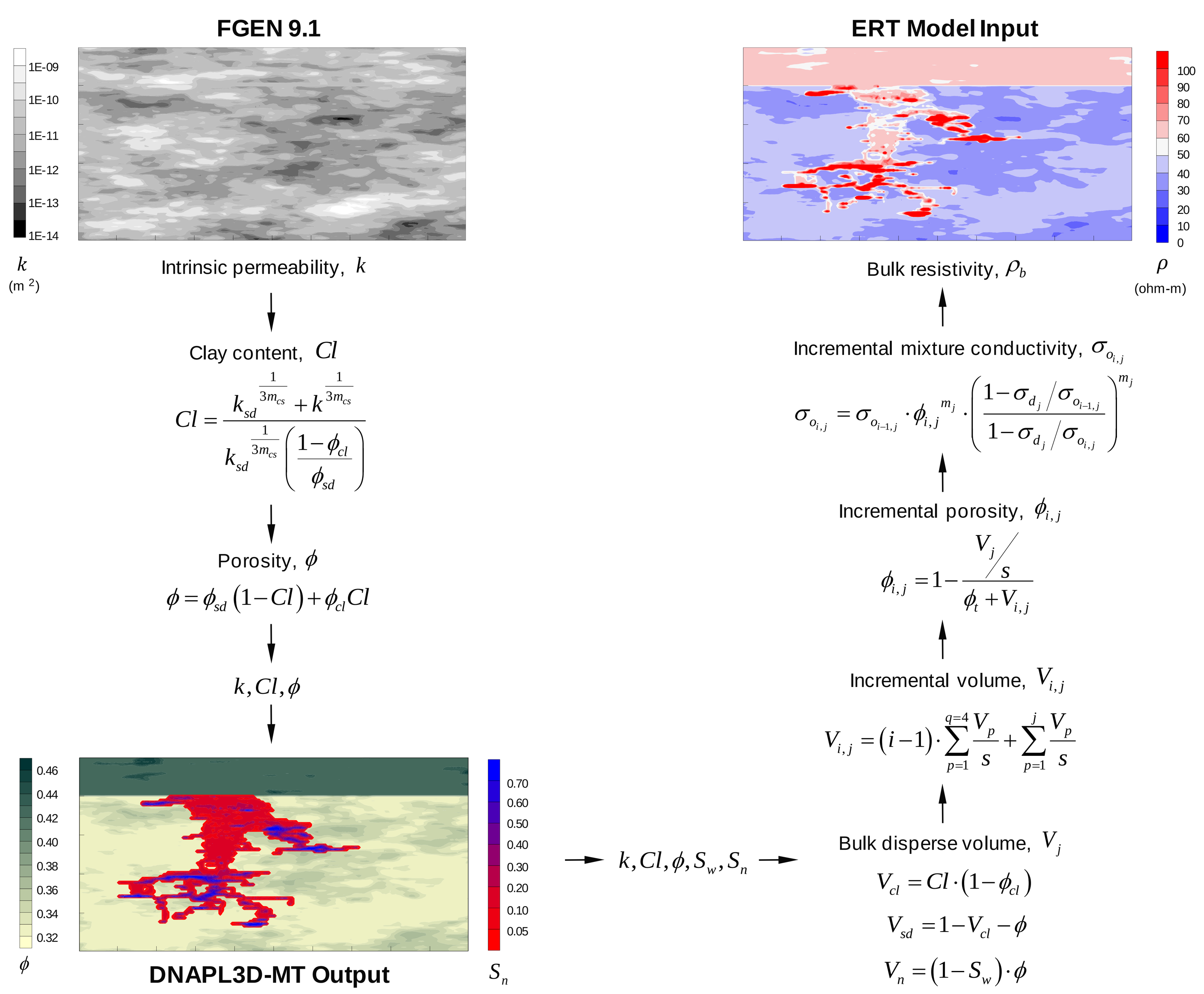

Figure 2. Schematic illustration of the DNAPL-ERT model coupling methodology

IP Monitoring of DNAPL

The geoelectrical package IP4DI, which allows 4D time-lapse inversion of ERT, time-domain and frequency domain IP, has demonstrated improved time-lapse images of changes over time (Karaoulis et al., 2013; Power et al., 2014). Since a sophisticated linkage methodology is not yet developed between the DNAPL model and the spectral IP component of the IP4DI package, a hypothetical DNAPL spill is presented. Figure 3a presents a DNAPL spill with spectral IP attributes as it migrates over three time-steps, with the resulting 4D inverted spectral IP images presented in Figure 3b. As shown, the time-lapse results are in good agreement with the initial model.

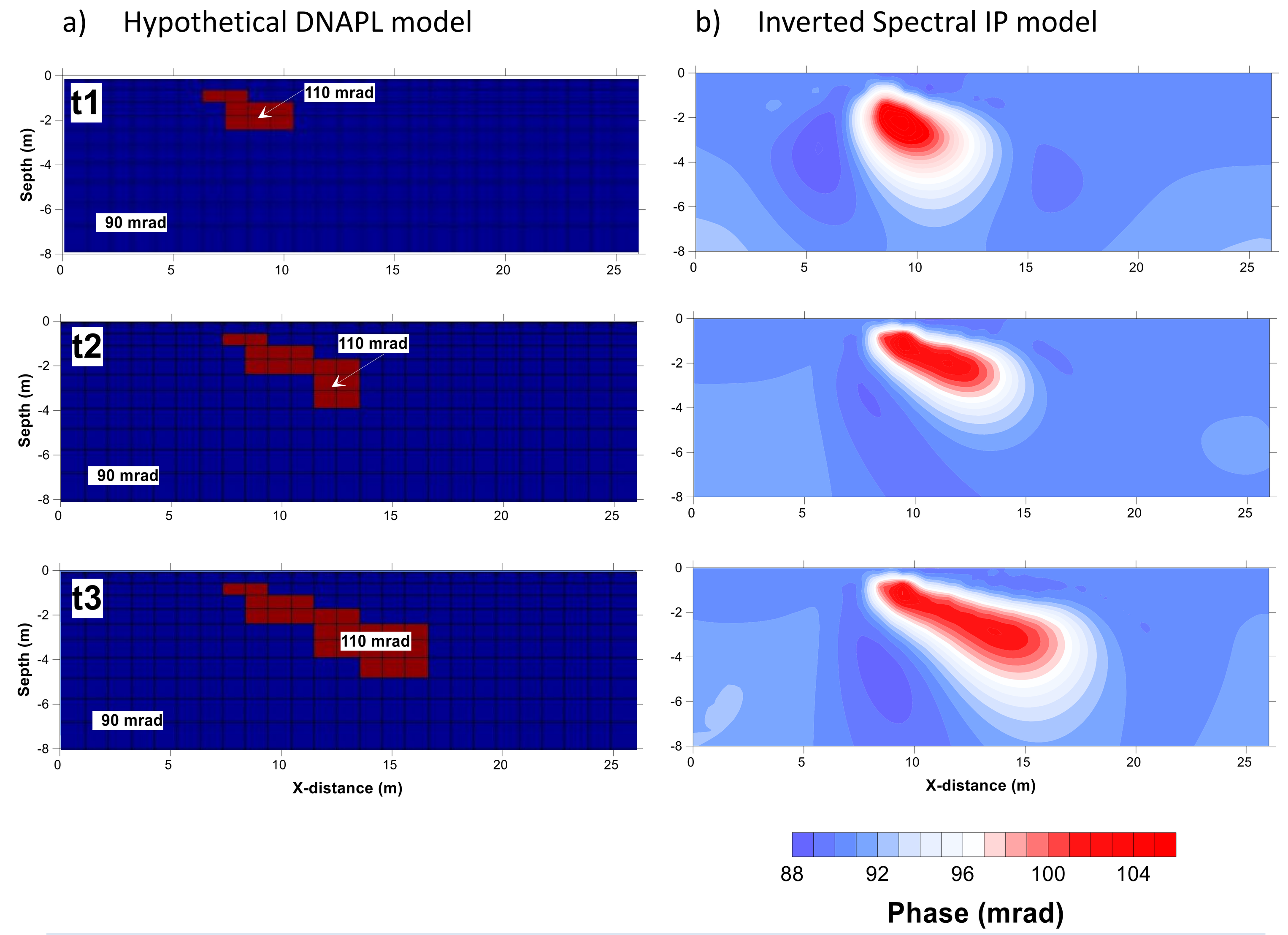

Figure 3. a) Spectral IP model simulating a hypothetical DNAPL spill at three time-steps, and b) the resulting 4D inverted spectral IP images

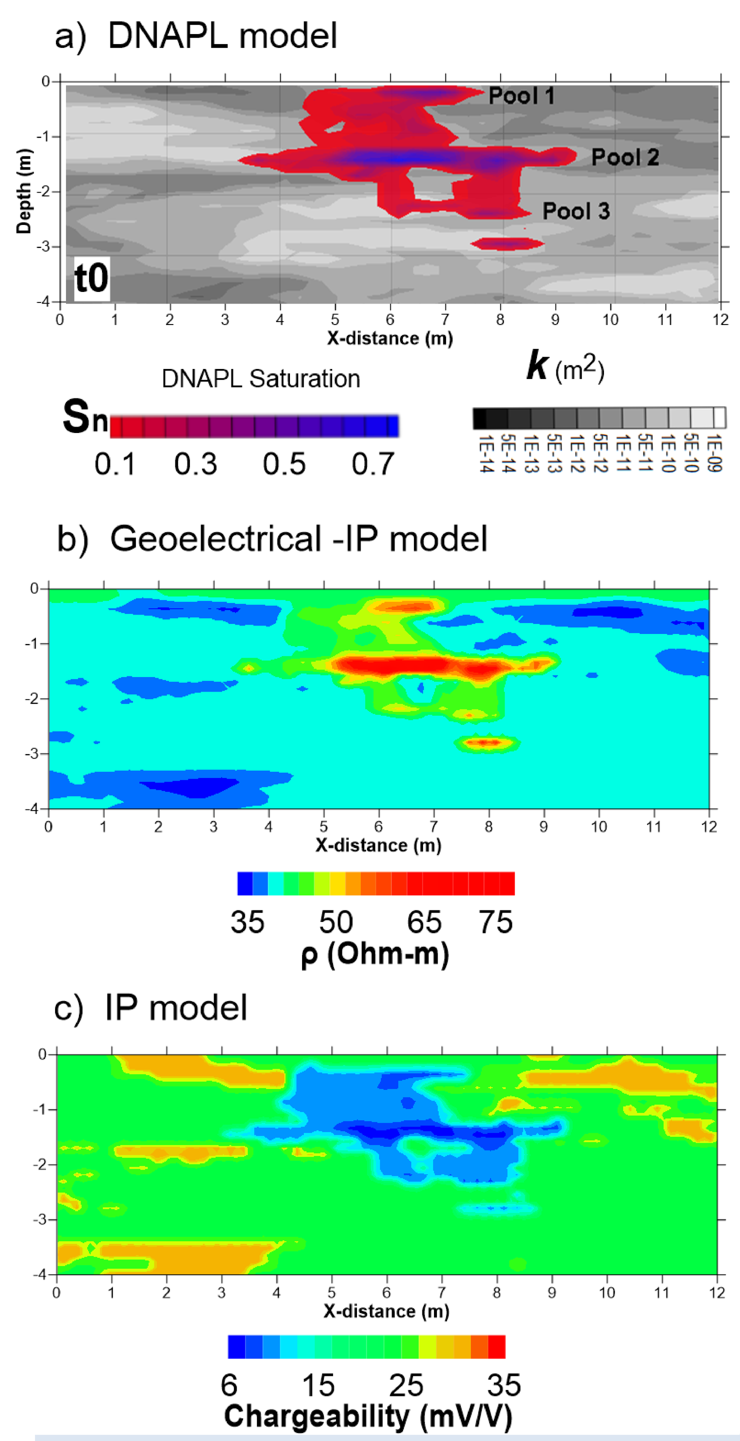

Figure 4. a) DNAPL spill model converted to: b) geoelectrical model, and c) chargeability model

Considering the IP modelling, the DNAPL domain can be converted to its corresponding resistivity using the current DNAPL-ERT linkage method as shown in the example of Figures 4a and 4b. We can assume that the DNAPL is interconnected between several pores and pore throats and is expected to suppress polarization mechanisms, resulting in lower chargeability (e.g., Johansson et al., 2015). In contrast, areas of clay content are expected to increase the chargeability. Following these assumptions, a simplified conversion method is used to obtain IP model domains from the DNAPL model domains: appropriate chargeability values are assigned as a function of DNAPL saturation and clay content, and representative IP model domains are obtained (Figure 4c).

The methodology was applied to a realistic and complex DNAPL spill scenario. In Figure 5, the remediation of a DNAPL source is simulated, with Figure 5a showing the DNAPL source zone prior to remediation (t0), and following removal of 30% (t1), 60% (t2), and 80% (t3) of the original DNAPL mass. The resulting 4D inverted resistivity and chargeability models are shown in Figures 5b and 5c, respectively, while the chargeability ratio of the successive time lapse images is shown in Figure 5d. It is evident that the original DNAPL distributions and associated changes over time are monitored quite satisfactory.

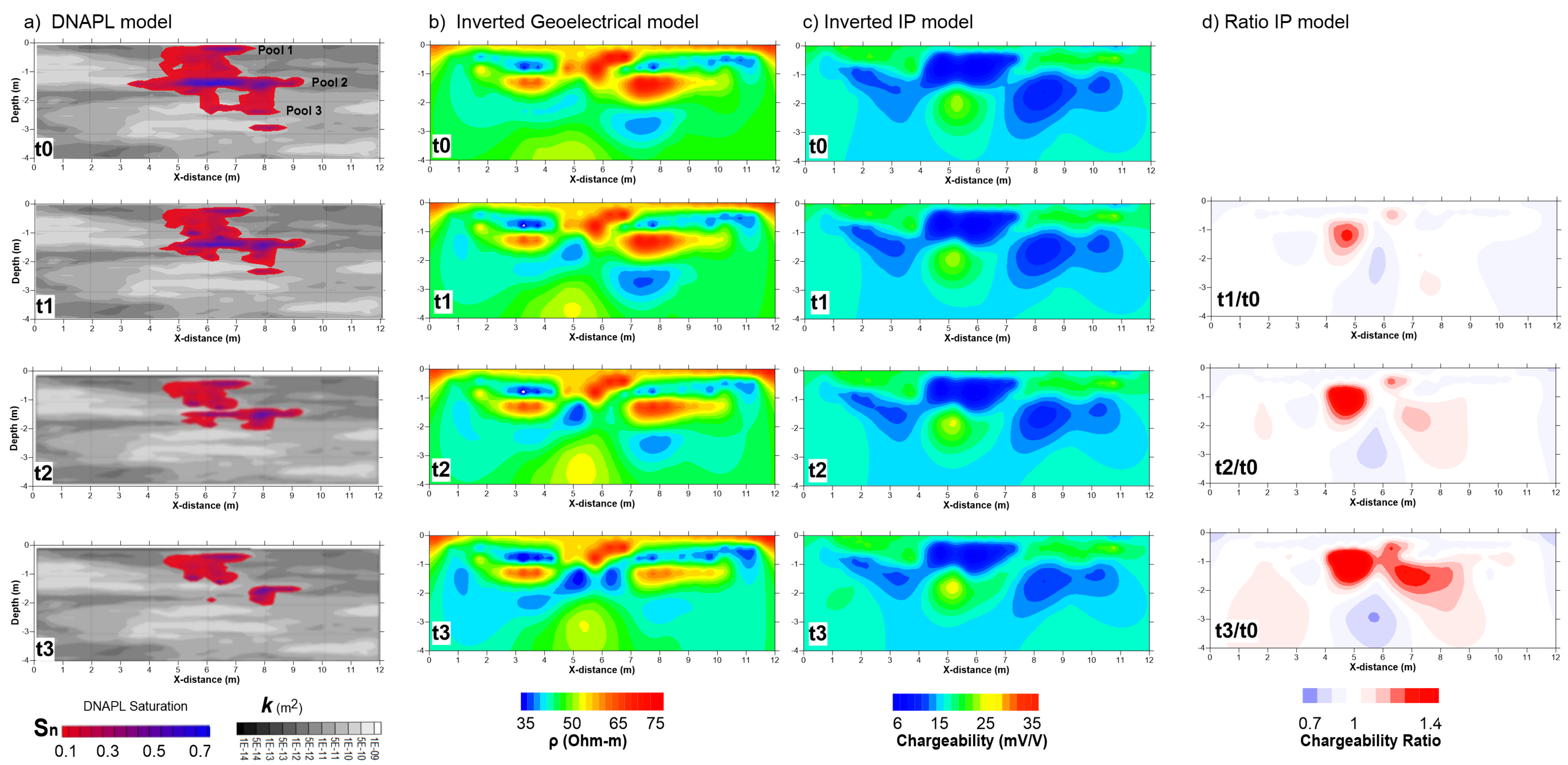

Figure 5. a) Simulated DNAPL remediation scenario after 0% (t0), 30% (t1), 60% (t2), and 80% (t3) of the original DNAPL mass has been removed, b) resulting 4D inverted resistivity, c) resulting 4D inverted chargeability, and d) chargeability ratio images.

Concluding Remarks

We have proposed a modelling approach and presented the appropriate tools in order to explore the potential of combined time-lapse ERT and induced polarization techniques for monitoring DNAPLs. Preliminary synthetic results are encouraging. Current work is being undertaken to investigate and develop more advanced linkage models between DNAPL scenarios and the corresponding IP responses.

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