

Linking Ground Deformation to Subsurface Anisotropy: Integrating InSAR, PDE Modeling, and Bayesian Inference

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Abstract:

Groundwater is the hidden lifeline of our planet — yet understanding how it moves beneath our feet remains a major scientific challenge. In fractured aquifers, water doesn't flow uniformly but follows preferential pathways shaped by cracks and faults, creating anisotropy. In this work, we explore how InSAR (Interferometric Synthetic Aperture Radar) observations of ground deformation can reveal these hidden flow directions. Using a 3D poroelastic finite element model of the Anderson Junction aquifer (Utah), we show that anisotropic hydraulic conductivity (AHC) produces a distinct, elliptical displacement signature detectable by InSAR. To move beyond deterministic modeling, we construct a stochastic prior model of the AHC tensor that quantifies uncertainty in both fracture orientation and magnitude. Building on this, we develop a Bayesian framework that couples Firedrake (for PDE simulation) with NumPyro (for probabilistic inference). Our results demonstrate the promise of remote sensing-driven inversion as a next-generation approach for characterizing and managing aquifers.