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The Prediction-Focused Approach: An opportunity for hydrogeophysical data integration and interpretation

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Hydrogeophysics is an interdisciplinary field of sciences aiming at a better understanding of subsurface hydrological processes. If geophysical surveys have been successfully used to qualitatively characterize the subsurface, two important challenges remain for a better quantification of hydrological processes: (1) the inversion of geophysical data and (2) their integration in hydrological subsurface models. The classical inversion approach using regularization suffers from spatially and temporally varying resolution and yields geologically unrealistic solutions without uncertainty quantification, making their utilization for hydrogeological calibration less consistent. More advanced techniques such as coupled inversion allow for a direct use of geophysical data for conditioning groundwater and solute transport model calibration. However, the technique is difficult to apply in complex cases and remains computationally demanding to estimate uncertainty.

In a recent study, we investigate a prediction-focused approach (PFA) to directly estimate subsurface physical properties from geophysical data, circumventing the need for classic inversions. In PFA, we seek a direct relationship between the data and the subsurface variables we want to predict (the forecast). This relationship is obtained through a prior set of subsurface models for which both data and forecast are computed. A direct relationship can often be derived through dimension reduction techniques.

PFA offers a framework for both hydrogeophysical “inversion” and hydrogeophysical data integration. For hydrogeophysical “inversion”, the considered forecast variable is the subsurface variable, such as the salinity. An ensemble of possible solutions is generated, allowing uncertainty quantification. For hydrogeophysical data integration, the forecast variable becomes the prediction we want to make with our subsurface models, such as the concentration of contaminant in a drinking water production well. Geophysical and hydrological data are combined to derive a direct relationship between data and forecast.

We illustrate the process for the design of an aquifer thermal energy storage (ATES) system. An ATES system can theoretically recover in winter the heat stored in the aquifer during summer. In practice, the energy efficiency is often lower than expected due to spatial heterogeneity of hydraulic properties combined to a non-favorable hydrogeological gradient. A proper design of ATES systems should consider the uncertainty of the prediction related to those parameters. With a global sensitivity analysis, we identify sensitive parameters for heat storage prediction and validate the use of a short term heat tracing experiment monitored with geophysics to generate informative data. First, we illustrate how PFA can be used to successfully derive the distribution of temperature in the aquifer from ERT during the heat tracing experiment. Then, we successfully integrate the geophysical data to predict medium-term heat storage in the aquifer using PFA. The result is a full quantification of the posterior distribution of the prediction conditioned to observed data in a relatively limited time budget.